Schoeller & Seavert

Strength of Concrete in Shear and Compression

Civil Engineering

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1906

STRENGTH OF CONCRETE

IN

SHEAR AND COMPRESSION

BY

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THESIS

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This is to certify that the following thesis prepared under the direction of Professor A. N. Talbot, Head of the Department of Theoretical and Applied Mechanics, by

JULIUS ERNEST SCHOELLER and NORMAN EDWARD SEAVERT

entitled STRENGTH OF CONCRETE IN SHEAR AND COMPRESSION

is hereby approved by me as fulfilling this part of the requirements for the Degree of Bachelor of Science in Civil Engineering.

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Head of Department of Civil Engineering

1906
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INTRODUCTION.

Concrete is being used so extensively at the present time, and reinforced concrete is becoming of such great value in building construction that more data upon the various methods of failure of this material and upon its allowable working stress in tension, compression and shear is needed. Especially is this true of shear. So few experiments have been made upon this subject, with such a wide variation of results that no definite allowable working stress can safely be stated. The reason for this variation in experimental results is due, no doubt, to the different ways of making shear tests and, also to the different forces which seem to exist besides that of shear.

With compression it is different. Many tests have been made for determining the strength of concrete in compression and these tests have agreed so well, that today we have a definite value for the allowable working stress of plain concrete in compression.

A brief history of some of the experiments which have been made for the determination of the shearing strength of concrete will be given, so as to give some idea of the vast variation of results.

In 1879 Prof. Bauschinger made some tests upon mortar specimens and found that the shearing strength was about 20% in excess of the tensile strength. Prof. C. B. Smith made a series

of tests upon three bricks cemented together, the middle one projecting out beyond the other two, and the load being applied so as to avoid any transverse bending. These tests are of little value on account of the materials used. M. Christophe maintained that tensile strength was greater than that of shear, and allowed a working value of only 21 to 35 pounds per square inch. M. Feret concluded that shearing strength was from 16% to 20% that of compressive strength, while M. Considere said that the shearing strength was 20% to 30% greater than tensile strength. These latter two agreed in allowing, as a working value for shear, $\frac{1}{8}$ of the compressive strength, or about 50 lb. per sq. in. These tests are probably the basis for the New York Regulations for Concrete. Lately Prof. Spofford conducted some tests at the Massachusetts Institute of Technology, from which he concluded that the shearing strength of concrete and mortar is not far from one-half the strength in direct compression. That is, the shearing strength is 50% of the compressive strength. The specimens used were 5 inches in diameter by $15\frac{1}{2}$ inches long, held in cylindrical bearings $5\frac{1}{2}$ inches apart; the load being applied from above through a half-cylindrical bearing 5 7/16 inches in length.

Many tests have been made upon reinforced concrete beams in which the cracks which extended downward, were thought to be shear cracks. But since it has been concluded that these cracks result from vertical shear and horizontal tension.

It is the purpose of this investigation to determine the value of plain concrete in shear, by means of different specimens and the strength and coefficient of elasticity of plain con-

crete in compression. The coefficient of elasticity is stated as being the ratio of the unit stress to the unit deformation, within the elastic limit of the material. This is not true of concrete in compression, as the ratio $\frac{\text{unit stress}}{\text{unit deformation}}$ within the elastic limit, is not a constant factor for any great range of stress. Nor is there any well defined elastic limit for concrete. There are three methods for computing the coefficient of elasticity of concrete in compression. They are (1) the tangent method; (2) the secant method and (3) elastic deformation. By the tangent method the coefficient of elasticity expresses the rate at which the stress increases at some particular point. By the secant method a factor is obtained by which to multiply the deformation to obtain the stress. By the third method the coefficient of elasticity expresses the ratio of stress to elastic deformation. The secant method shall be employed in this investigation.

DESCRIPTION OF MATERIALS.

The stone used was Kankakee limestone. It was screened over a $\frac{1}{4}$-inch screen through a one-inch screen. It contained 54% voids.

The sand was of good quality, sharp and clean, and contains about 28% voids. The mechanical analysis is shown in following table.

The cement used was a mixture of four or five different standard brands of Portland cement, the mixture being reground. Tensile strength was as shown in the following table.

The sand and cement were mixed dry; the stone was added and turned several times, after which water was added and the mass mixed until it was uniform in appearance. Enough water was used so that it flushed to the top after light tamping.

TABLE A
Sand Analysis

Sieve Number	Per Cent Passing
4	100
10	73
20	36
30	12
74	5
100	2

TABLE B
Tensile Strength of Cement

Ref. No.	Age 7 days		Age 60 days	
	Neat	1:3	Neat	1:3

DESCRIPTION OF TEST SPECIMENS

SHEAR.

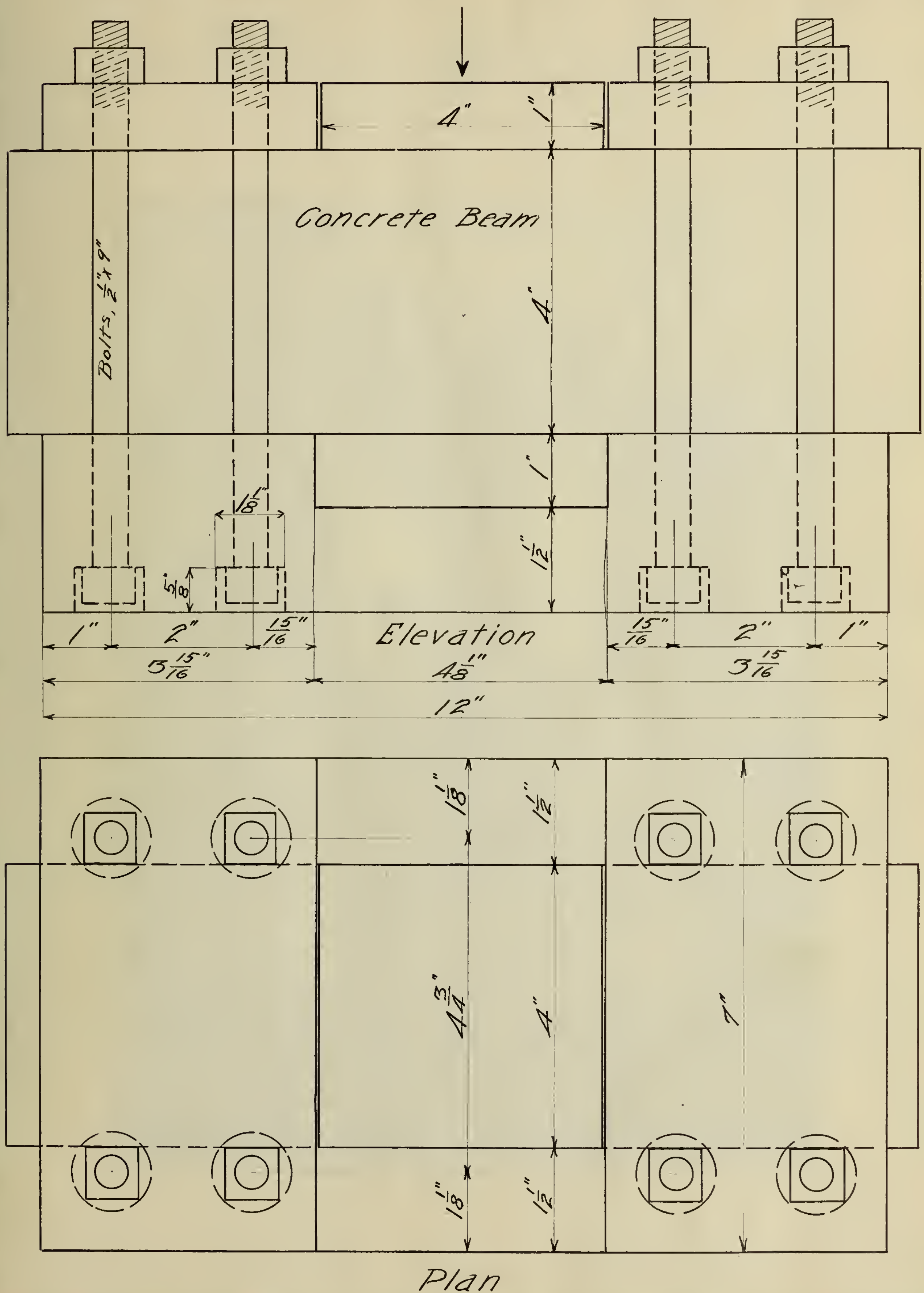
To have this investigation accomplish its main object it was necessary that the specimen decided upon should be such as would fail by shear alone, as far as it was possible to make them so. The specimens used in Messrs. O'Connell & Shoemaker's thesis, presented June 1905, gave good results and the specimens used in the investigation were along the same design with the exception of class "A" which will be described first.

In order to test for shear as it is more likely to be found in practice, a small beam 4x4x13 inches was decided upon. It was to be tested as a restrained beam; that is, uniformly loaded with the ends clamped to the supports. This specimen will be known as class "A".

The other specimens were designed along different lines. These were simply blocks, through which a hole was punched. It was thought that if the body of these blocks was made thicker than the actual shearing section it would tend to resist the horizontal tensile forces which are induced by the vertical compression, resulting from the vertical load, and which tend to break the specimen by tension. Two kinds of specimens were made to test this assumption. One was simply a slab 13 inches square by 3 inches thick and will be known as class "B". (Plate 2, page 9) The other was a block $12\frac{1}{2}$ inches square and 5 inches thick, having an inset in the center of it two inches deep, leaving a net

Plate I_A

"Apparatus for Testing Shear Specimens, class "A."



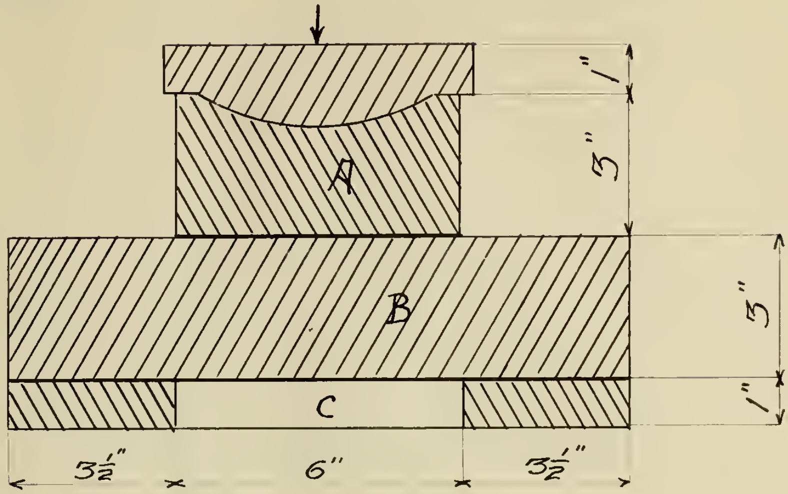
Method of Applying Load
for Shear Specimen, Class "A."

shearing section of 3 inches deep. This specimen will be known as class "C", shown on plate 3 page 10. The inset was a beveled cylindrical hole $6\frac{1}{8}$ inches in diameter at the top and 7 inches in diameter at the bottom by 2 inches in depth. As stated above, the application of the vertical load tends to spread out the concrete within the shearing section. This tendency is resisted by the surrounding concrete and "induced tension" is the result. A reinforced specimen was adopted to resist this "induced tension". This specimen was of the same dimensions as that of class "C" and will be known as class "D", shown on plate 4 page 11. The reinforcement used was an iron hoop of 9 inches inside diameter and made from a $1x\frac{1}{4}$ inch iron bar. This hoop was placed so that its upper edge came about $\frac{1}{2}$ inch above the top of inset. Reason for this will be explained later.

The form used in making the test specimens of classes "C" & "D" is shown in plate 5 page 12. The base platform was 18x20 inches and consisted of two $10x\frac{5}{4}$ inch planks nailed together and fastened by 2x2 inch cross sticks, which served as rests so that platform did not lay upon the floor. Then to the center of this platform was screwed a beveled cylindrical block, 2 inches thick and $6\frac{1}{8}$ inches small diameter by 7 inches large diameter. It was sawed into three pieces as shown in drawing. The sides consisted of $5x\frac{3}{4}$ inch planking which were bolted together and held in place by wooden strips nailed to the platform. The inside dimensions were $12\frac{1}{2}x12\frac{1}{2}$ inches. The reason for sawing the inset block into three pieces was this:- The contraction of the concrete and the expansion of the wooden block, due to the absorption of

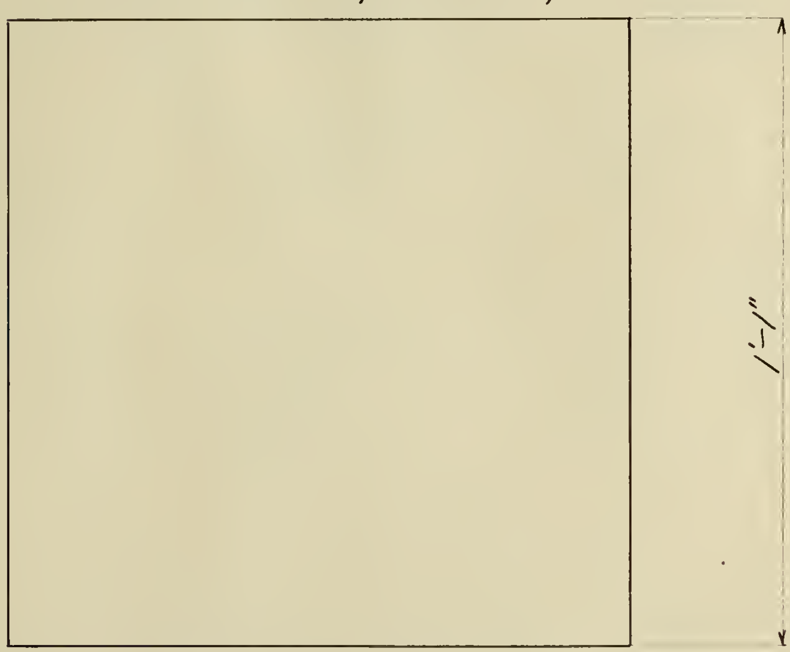
Method of Applying Load

Fig. 1

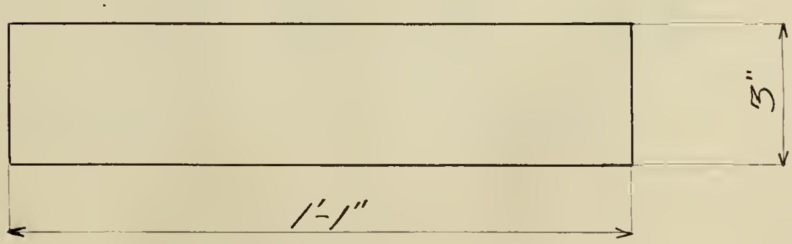


Shear Test Specimen, Class B.

Fig. 2.

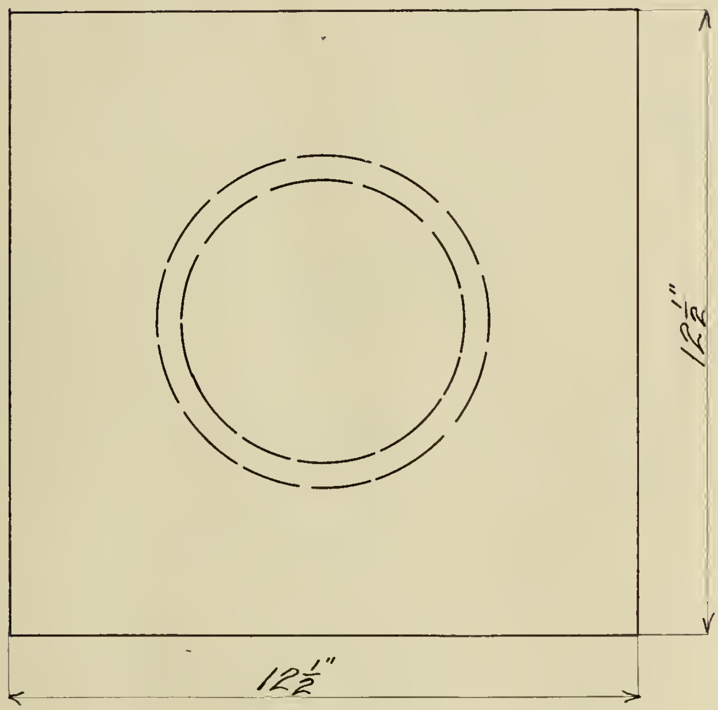


Plan



Elevation

Shear Test Specimen, Class "C."



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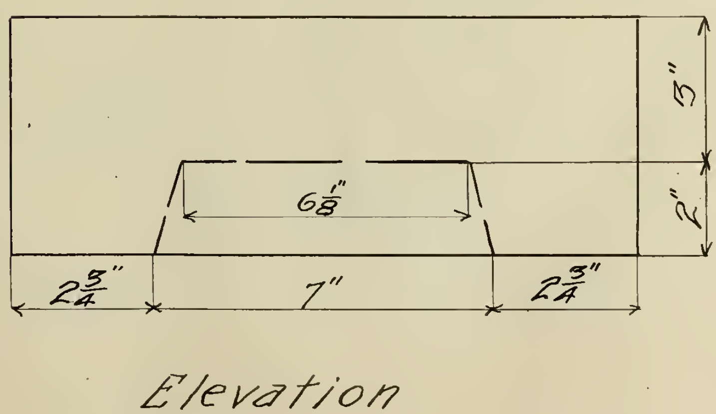
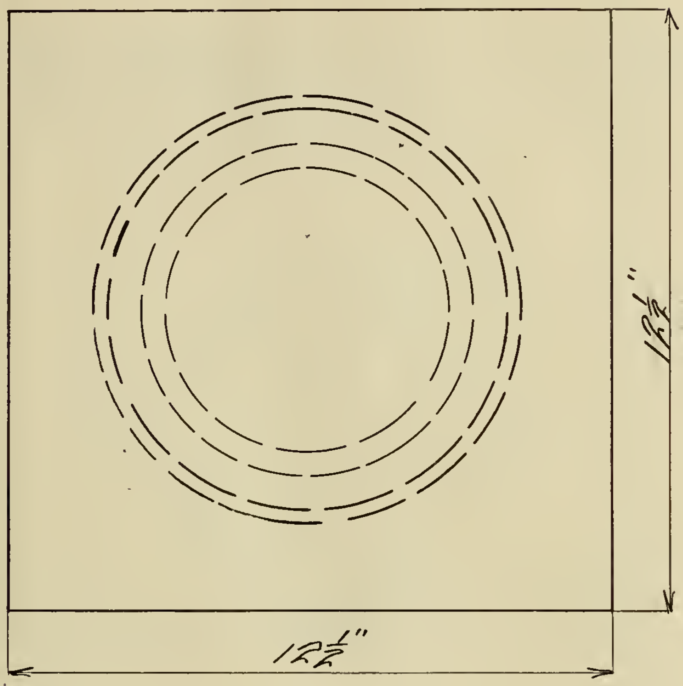


Elevation

Plate 4

Shear Test Specimen, Class "D"



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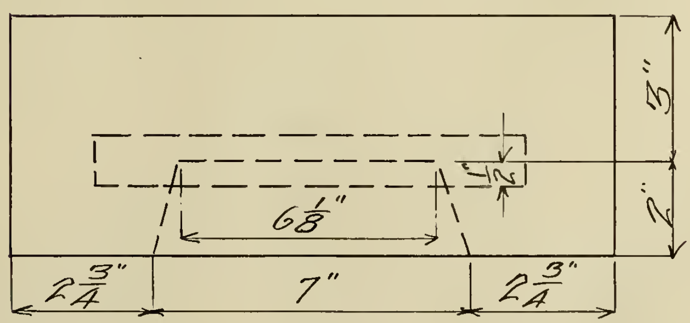
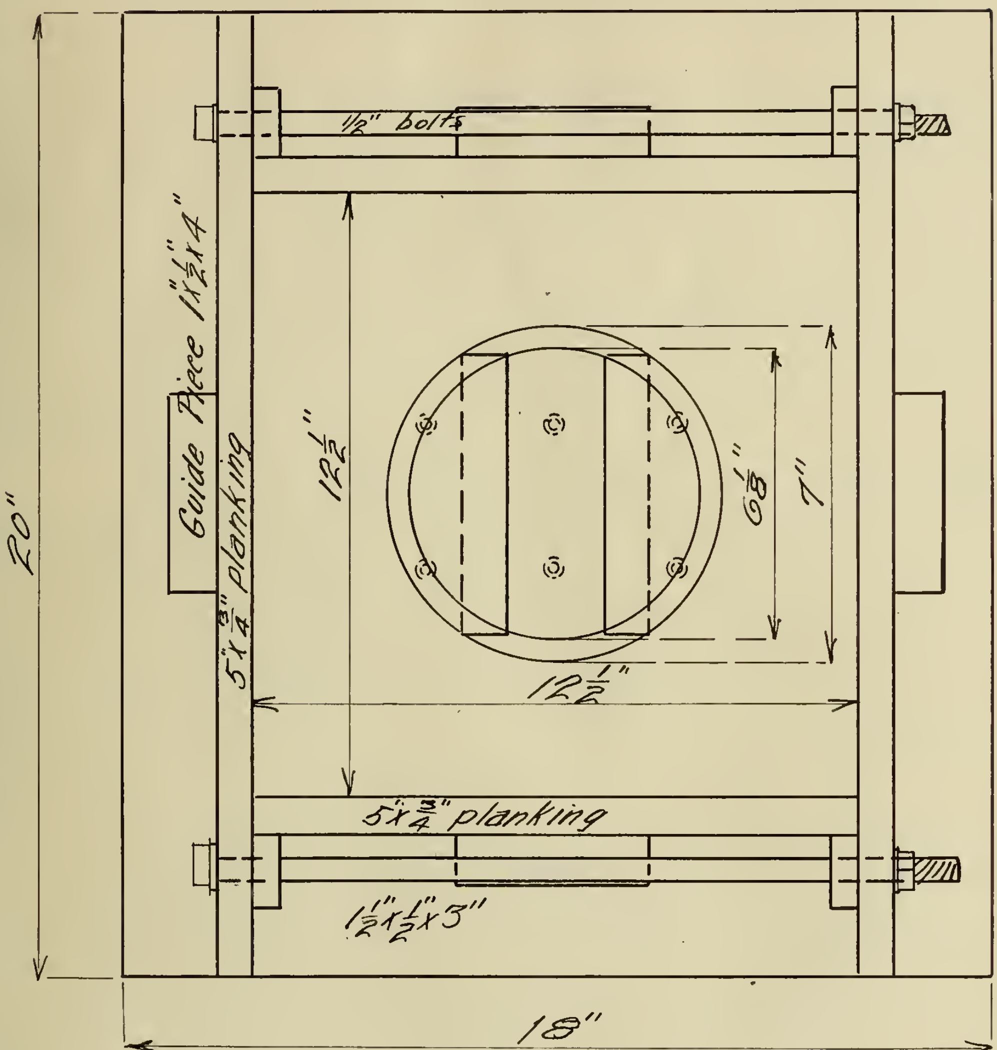


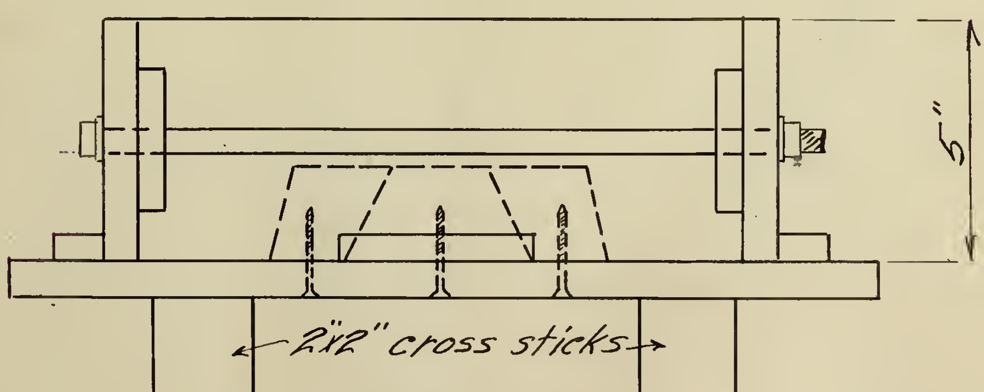
Elevation

Plate 5

Form for Specimens of Class "C" + "D"

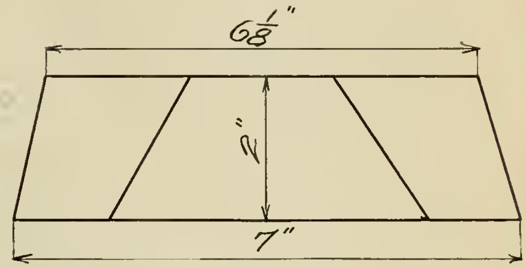


Plan



Elevation

water, wedged this block in the specimen. If this block was in one piece it could not have been removed without injury to the specimen. Hence this block was sawed in three pieces as shown. Even then each time a specimen was removed from its mold this block had to be unscrewed from the platform and pulled out. Oil was soaked into it before using but this did not help. The only remedy for this is to use an iron block.



The forms used for class "B" were simply 4 3x$\frac{3}{4}$ inch planks bolted together was to form a 13x13 inch box.

For class "A" the forms were made of 4 4x$\frac{3}{4}$ inch planks bolted together so as to form a 4x4x13 inch box. No platform was used for classes "A" & "B" the forms resting upon heavy paper upon the floor.

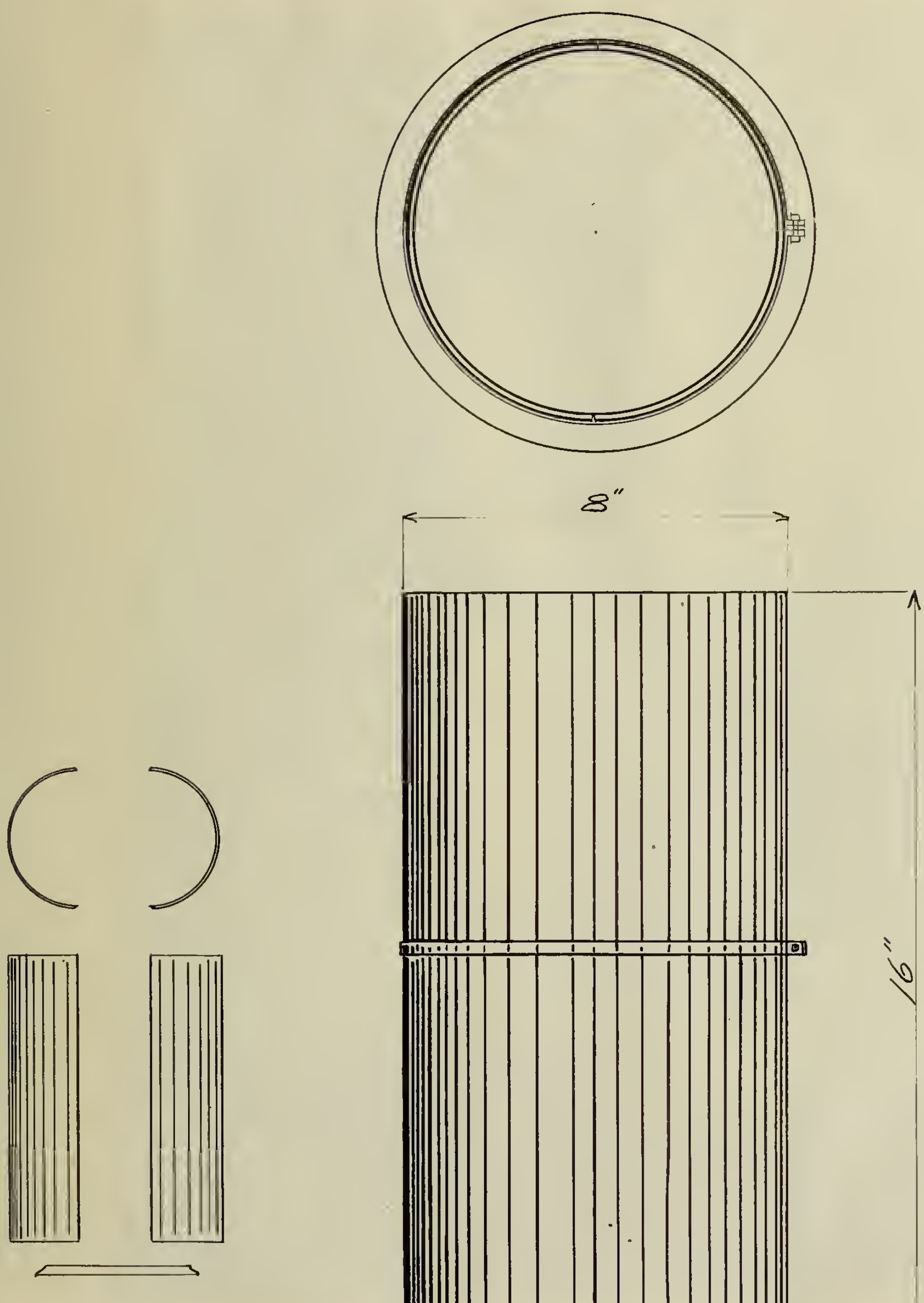
Ten specimens were made of each class, five being of a 1-3-6 mixture and five of a 1-2-4 mixture. The concrete was thoroughly tamped and spaded so as to give a uniform section and a smooth surface upon the sides. The top surface was covered with a thin coat of plastic mortar. The specimens were allowed to set in the forms for four days and were then stored in wet sand. The general length of time between making and testing the specimens was 60 days. The 1-2-4 specimens were taken out of the sand 3 days before testing, as it was thought that more representative results could be obtained by letting them dry out.

COMPRESSION.

The specimens used were the standard 8 inch cylinder, 16 inches long, and the six inch cube. The cylinders were used to determine the coefficient of elasticity and the crushing strength, while the cubes were used to determine the crushing strength only.

The forms used for the cylinders consisted of two semi-circular pieces of iron 16 inches long which fitted into a bed plate and were held together by means of an iron band, as shown in plate 6A page 15. The cube forms were made of 6x1$\frac{3}{4}$ inch planking and were in the form of a box divided into three parts, each part being about 6x6x6 inches. These dimensions were variable as the form was not always set up in the same manner; that is, the same pieces in the same places. There were eleven cylinders made, six of 1-3-6 mixture and five of 1-2-4 mixture. There were thirty cubes made, fifteen being made from each mixture of concrete. The method of making and storing was the same as for the shear specimens described above.

Cast Iron Form for Cylinders



Method of Testing Cylinders

DESCRIPTION OF TESTS.

The tests were made on an Olsen machine of 200000 pounds capacity (This machine is generally used as a 100000-pound machine but by placing a weight upon the end of the lever arm it could be used as a 200000-pound machine). The slowest speed of the machine was used, it being .04 inch per minute.

SHEAR.

Loads were applied continuously up to the ultimate load, the first appearance of cracks, or other signs of failure, and the ultimate load being noted. Method of applying load is shown on plates 1B + 2 pages 7 + 9. On plate 2 page 9 "A" is a spherical bearing block through which the load is transmitted. "B" is the test specimen and "C" is a cast iron bearing plate, 13 inches square, 1 inch thick with a 6 inch circular hole in the center. In order to get an even bearing between surfaces, plaster of Paris was applied to the bearing surfaces and allowed to set, under a light load, for about six minutes.

COMPRESSION.

In the cube tests the load was applied perpendicular to the layers of concrete and was continued up to the ultimate load; the first signs of failure and ultimate load being noted. In the cylinder tests extensometers were placed upon the cylinders as shown in plate 6B page 16. These were placed 10 inches apart and 3 inches from each end of the cylinder. The load was run up by

increments of 4000 pounds, to the ultimate load. By means of a vernier these extensometer read to .0001 of an inch. Load was applied as shown in plate 6B page 16, and plaster of Paris used for all bearing surfaces.

OBSERVED DATA

SHEAR

The first signs of failure in the specimens of class "A" were tension cracks, as shown in the sketches on page 21. In specimens number 1 to 6 the cracks appeared as shown in sketch 1, and occurred from three-fourths of the maximum load up to within a few hundred pounds of the maximum load. As the load increased these cracks gradually lengthened and widened, as shown in sketch 2, until they were about 1/16 inch wide at the top.

In the specimens number 7 to 10 the first signs of failure were tension cracks as shown in sketch 3. These vertical cracks would appear from one-third to four-fifths of the maximum load, and would gradually lengthen and widen as the load increased. Following these cracks, other cracks would appear the same as were first noticed in specimens number 1 to 6. These appeared as is shown in sketch 4. After the maximum was reached the lower crack would gradually close up, while the two upper cracks would increase in width, thus showing that the manner of failure was along these lines.

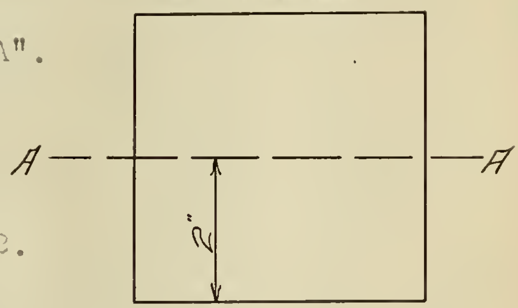
The beam was tested as a restrained beam and when loaded, the beam would tend to deflect, thus pushing the two ends against the clamps. This developed tension in the upper fiber, and thus, the two upper cracks are accounted for. Tension was also developed in the lower fiber and caused the lower crack shown in sketch 3. Why this crack should form in some specimens and not in all, is difficult to say. It may have been that the bearing of the

clamps was not the same for all cases, but this is improbable. A spreading apart of the clamps on top was noticed, which was probably due to the loose fit of the bolts in the holes. This fact increased the tendency of the beam to break into three separate parts.

The bending moment of a restrained beam at the middle, when uniformly loaded is $\frac{Wl}{24}$, that is the total load X length of span in inches divided by twenty-four. In sketch 4 the load is 31500 pounds, and the span is 4 inches. So that $\frac{31500 \times 4}{24} = 5250$ pound-inches = bending moment. $S = \frac{Mc}{I}$ will give the stress in the lower fiber, in which "M" is the bending moment, "I" the moment of inertia about the axis "AA", and "C" the distance of the most remote fiber from the axis "AA".

$$I = \frac{4 \times 4 \times 4 \times 4}{12} = \frac{64}{3} \qquad C=2$$

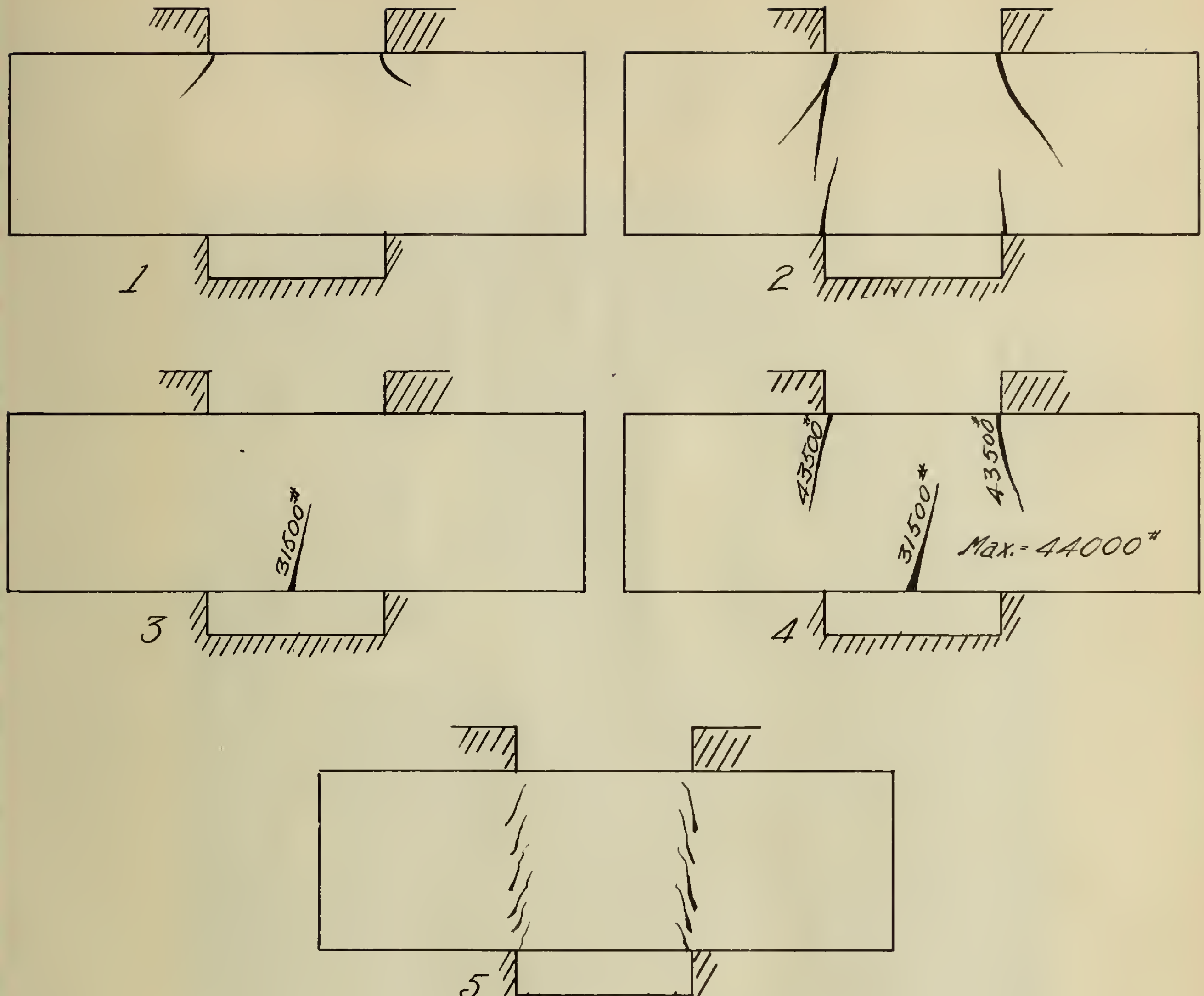
$$S = \frac{5250 \times 2}{64/3} = \frac{5250 \times 3 \times 2}{64} = 492.$$



Thus the tensile stress in the lower fiber, for this particular case, is 492 lb. per sq. in.

In all cases cracks formed as shown in sketch 5. It is believed that these cracks are shear cracks. Of course there was some crushing along these lines, but crushing will always appear in shear tests of concrete. The failure was so marked along these lines that, it is believed, shear was the governing element.

In classes "B" "C" & "D" the manner of failure was the same. From one-third of the maximum load up to within a few hundred pounds of the maximum load, cracks developed upon all four sides of the rectangular specimen, starting from the bottom and



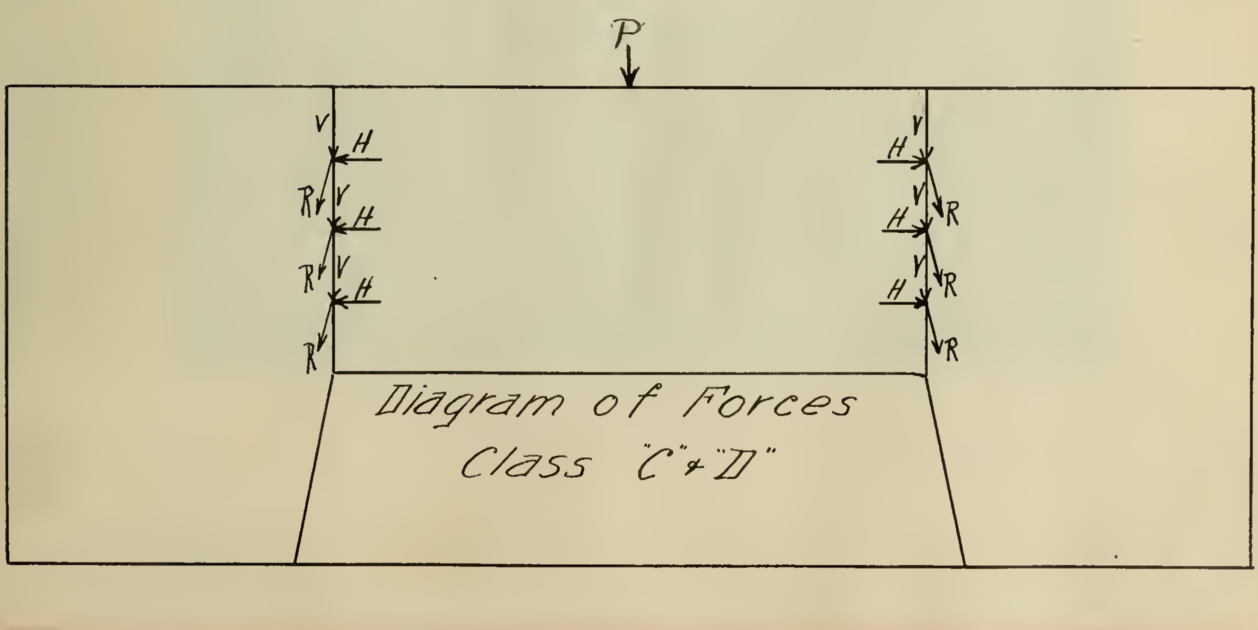


Diagram of Forces
Class "C"+"D"

Manner of Failure and
Method of Applying Load
Shear Specimen, Class "C" & "D".

increasing in length towards the top. At first they were very small, but when the maximum load was reached they were about 1/16 inch wide at the bottom, as shown in plate 8 page 22. These cracks so formed as to leave the specimen in five separate parts. That is the surrounding concrete separated from the shearing portion in four parts. Cracks also formed on the bottom of the shearing portion, running crosswise. In no case did the shearing section break.

These cracks are tension cracks and are developed in the following manner. In the diagram on page 21 "P" is the vertical load and its force developes the forces "V" along the shearing section. Also, due to this force "P", the concrete within the shearing section tended to spread out, and hence developed the forces "H". The forces "V" and "H" combine and form the diagonal force "R". These diagonal forces are the ones which cause the specimen to fail.

In class "D" the object was to so place the iron hoops as to resist the resultant of these diagonal forces. In specimen 17 of class "D" the hoop was broken, due to a poor weld. But this shows that the stress resisted by these hoops is very large. Specimen 6 of class "C" failed very suddenly, and the cracks opened very fast. This was probably due to the slipping of the specimen upon the iron base plate, which in turn, was due to the plaster of Paris not being allowed to set long enough.

COMPRESSION.

The first signs of failure noted in the cube tests were cracks along the edges, and sometimes midway between the edges.

These cracks occurred from one-half to nine-tenths of the maximum load. After these cracks formed the surface began to bulge and peel. Most of the specimens were crushed when the maximum load was reached.

No "first signs of failure" were noted in the cylinders, as none were detected until the maximum load was reached, or nearly so. In some cases, after the maximum load had been reached, the eye could detect no signs of failure. Trouble was encountered with one of the extensometers, which measured the unit deformation of the cylinders. It did not show any movement until the load was about one-fourth of the maximum bad. In cylinders numbers 1 A and 5 no trouble was had. The mean of the readings of the extensometers, for all the cylinders, was plotted, as it was thought best to do this.

Cylinder 7 was accidently broken before any readings could be taken.

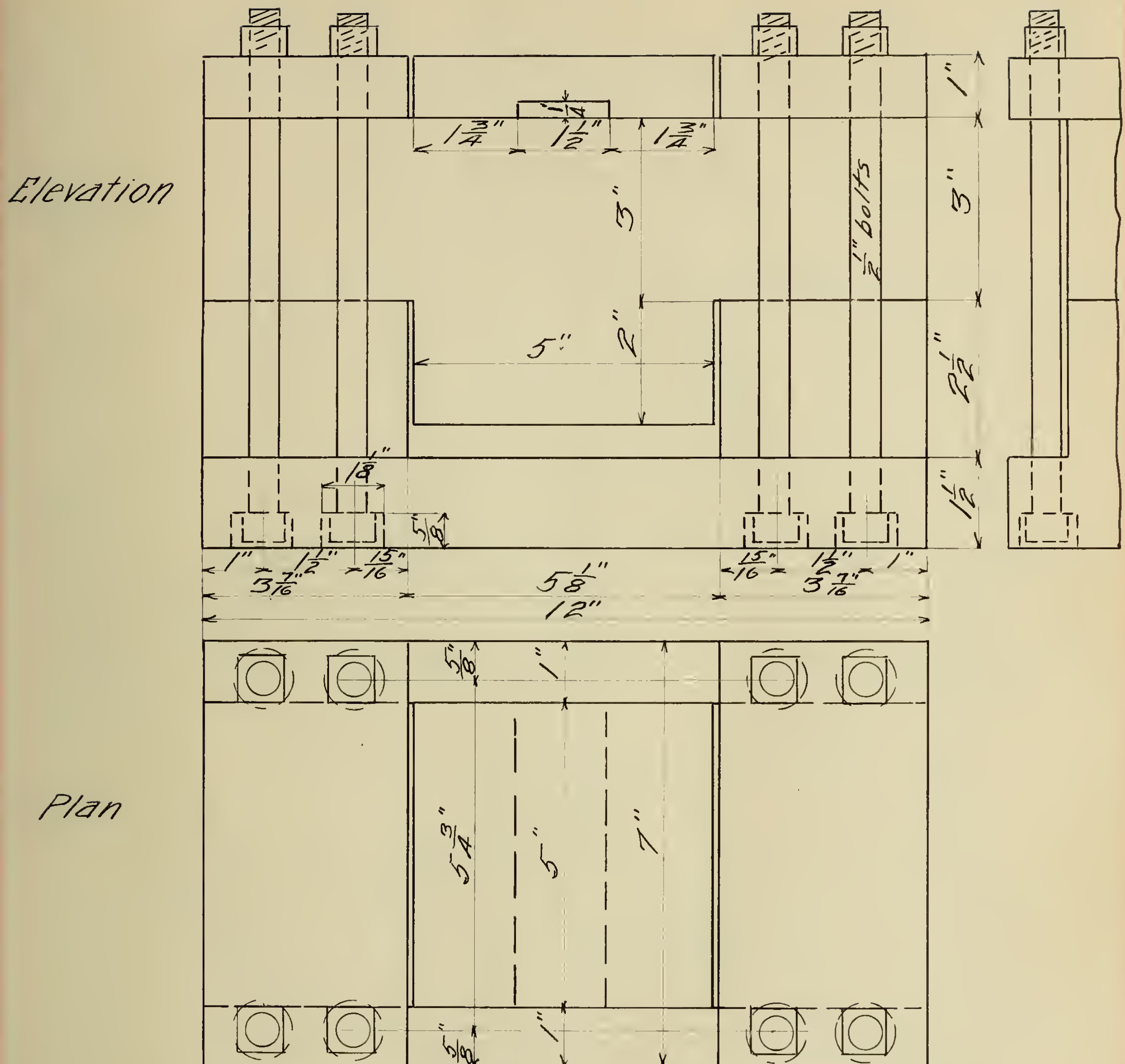
DISCUSSION OF RESULTS

SHEAR

From this investigation it is found that the shearing strength of a 1-3-6 mixture of concrete is 1820 lb. per sq. in., while the compressive strength is 2420 lb. per sq. in. In other words the shearing value is 75% of the compressive value for a 1-3-6 mixture. For a 1-2-4 mixture it is found that the shearing strength is 2140 lb. per sq. in., while the compressive strength is 3210 lb. per sq. in.; or, the shearing value is 67% of the compressive value for a 1-2-4 mixture. These values are higher than any before recorded with the exception of those obtained by Messrs. O'Connell and Shoemaker in their thesis presented June 1905. They found the shearing strength to be 80% of the compressive strength. The shearing value obtained in this investigation is much higher than that obtained by Messrs. O'Connell and Shoemaker. But the ratio of increase of the shearing value is not in proportion to that of the compressive values, upon which the percentage was based. The cubes of this investigation showed a very high compressive strength.

The results of series number 5 were not taken into consideration, for any of the specimens, as this series was made with a different cement than that used for the other series.

The test specimens for shearing in this investigation are not satisfactory to the investigators. Classes "B" and "C" are of no value, and class "D" is, in fact, a combination of the two.



Proposed Test Specimen, and Apparatus, for Shear Tests.

In class "D" the correct position for the hoops is not certain, and hence it is recommended that two hoops should be used, One placed as it was in this series of tests, and the other placed one-half inch above it. This is to insure resistance to the diagonal forces, explained beforehand.

In class "A" a new specimen is recommended as shown in sketch on page 26. The moment arm, due to the enlarged section at the center, will enable the specimen to better resist tensile stresses due to beam action. It will also reduce the shearing section and, hence, allow the use of the bearing block shown to transmit the load. The use of this block will bring the point of application of the load nearer the reactions, and thus reduce the bending moment. With these changes better results could probably be obtained.

COMPRESSION.

For the 1-3-6 mixture of concrete the strength in compression was found to be 2420 lb. per sq. in. for the cubes and 1270 lb. per sq. in. for the cylinders. For the 1-2-4 mixture the cubes gave a strength of 3210 lb. per sq. in. while the cylinders gave a strength of 2430 lb. per sq. in. For the coefficient of elasticity of plain concrete in compression the reader is referred to the table on page 28.

Coefficient of Elasticity of Concrete in Compression.

Cylinder	Loads-Lbs. 0-250	250-500	500-750	750-1000
1-A	2,400,000	2,000,000	1,200,000	500,000
1-B	2,000,000	1,400,000	730,000	440,000
2	2,500,000	2,200,000	1,400,000	640,000
3	3,000,000	2,600,000	2,400,000	1,800,000
4	2,800,000	2,600,000	1,800,000	1,000,000
5	3,000,000	2,800,000	1,500,000	700,000
Mean 1-4	2,540,000	2,120,000	1,500,000	1,070,000
6	4,200,000	3,900,000	3,900,000	3,500,000
8	4,600,000	4,200,000	4,100,000	3,900,000
9	4,600,000	4,000,000	4,100,000	3,800,000
10	4,200,000	3,900,000	3,800,000	3,300,000
Mean	4,400,000	4,000,000	3,970,000	3,600,000

Table 1

Data and Results — Class A.

Reference No.	Age Days	Shearing Section: Width ins.	Thick-ness. ins.	Double Area sq. in.	Loads in lbs.: First Crack	Ultimate	Unit Shear lbs/□"
1	60	$4\frac{3}{16}$	$4\frac{1}{16}$	34.0	——	40500	1190
2	60	$4\frac{1}{4}$	$4\frac{1}{8}$	35.0	41200	48000	1371
3	61	$4\frac{1}{16}$	$4\frac{3}{16}$	34.0	46000	46500	1368
4	59	4	$4\frac{1}{4}$	34.0	33300	45000	1324 Mean 1313
5	60	4	$4\frac{1}{4}$	34.0	34000	34700	1020
	Mean of 1-3-6 mixture						1255
6	59	$4\frac{1}{8}$	$4\frac{1}{4}$	35.0	——	54000	1543
7	59	4	$4\frac{1}{4}$	34.0	31500	44000	1295
8	58	4	$4\frac{1}{4}$	34.0	46400	58400	1718
9	59	$4\frac{1}{8}$	$4\frac{3}{16}$	34.0	33400	49300	1450
10_A	57	$4\frac{3}{16}$	$4\frac{1}{8}$	34.5	29800	45800	1327
10_B	57	$4\frac{3}{16}$	$4\frac{1}{8}$	34.5	27000	40500	1175
	Mean of 1-2-4 mixture						1418

Table 2

Data and Results — Class B.

Reference No.	Age Days	Shearing Section: Diameter ins.	Thick-ness ins.	Area sq. ins.	Loads in lbs.: First Crack	Ultimate	Unit Shear lbs/sq. in.
1	60	$5\frac{7}{8}$	$3\frac{1}{8}$	57.8	28000	30800	533
2	60	"	$3\frac{5}{16}$	61.0	18000	64500	1058
3	61	"	$3\frac{3}{16}$	58.9	58000	60500	1028
4	59	"	$3\frac{1}{4}$	60.1	37800	61200	1003
5	60	"	$3\frac{5}{16}$	61.0	39500	59000	Mean 950 968
	Mean of 1-3-6 mixture						918
6	59	"	$3\frac{5}{16}$	61.0	24200	81000	1330
7	59	"	$3\frac{1}{4}$	60.1	22000	86800	1443
8	58	"	$3\frac{3}{16}$	58.9	16600	64500	1095
9	59	"	$3\frac{1}{4}$	60.1	12800	48000	799
10	57	"	$3\frac{5}{16}$	61.0	41800	79400	1300
	Mean of 1-2-4 mixture						1193

TABLE 3.

Data and Results — Class C.

Reference No.	Age Days	Shearing Section: Diameter ins.	Shearing Section: Thickness ins.	Shearing Section: Area sq. in.	Loads in lbs.: First Crack	Loads in lbs.: Ultimate	Unit Shear lbs/sq. in.
1	60	$5\frac{7}{8}$	$3\frac{3}{16}$	58.8	54000	66300	1126
2	60	"	$3\frac{3}{16}$	58.8	69400	69800	1187
3	61	"	$3\frac{1}{8}$	57.8	63300	69300	1198
4	59	"	$3\frac{1}{4}$	60.1	28000	63300	1052
5	60	"	$3\frac{1}{4}$	60.1	42000	54700	Mean 1139 910 1141
	Mean of 1-3-6 mixture						1095
6	59	"	$3\frac{1}{4}$	60.1	39300	66200	1100
7	59	"	$3\frac{1}{16}$	56.5	45,600	82700	1463
8	58	"	$3\frac{1}{8}$	57.8	41100	86500	1495
9	59	"	$3\frac{3}{16}$	58.8	26200	74400	1262
10	57	"	$3\frac{1}{8}$	57.8	19200	55900	967
	Mean of 1-2-4 mixture						1257

TABLE 4.

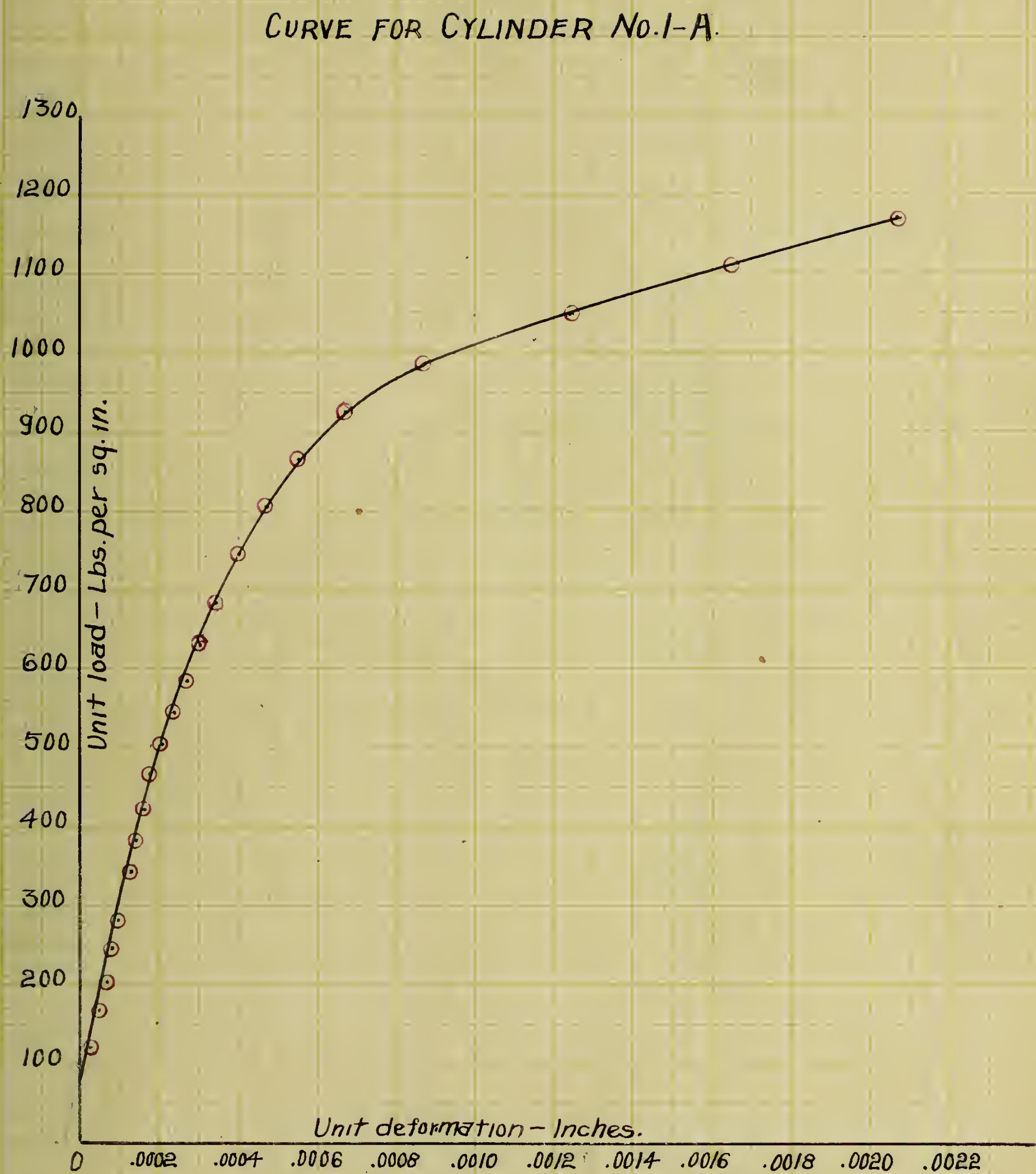
Data and Results — Class D.

Reference No.	Age Days	Shearing Section: Diameter ins.	Shearing Section: Thickness ins.	Shearing Section: Area sq. in.	Loads in lbs.: First Crack	Loads in lbs.: Ultimate	Unit Shear lbs/sq. in.
11	60	$5\frac{7}{8}$	$3\frac{5}{32}$	58.5	73000	89500	1529
12	60	"	$3\frac{1}{8}$	57.8	98000	105500	1825
13	61	"	$3\frac{1}{8}$	57.8	100000	108000	1869
14	59	"	$3\frac{1}{8}$	57.8	62300	119100	2060
15	60	"	$3\frac{3}{16}$	58.8	58200	91500	Mean 1821 1555
	Mean of 1-3-6 mixture						1768
16	59	"	$3\frac{1}{4}$	60.1	85300	145500	2420
17	59	"	3	55.2	37700	115500	2091
18	58	"	$3\frac{1}{8}$	57.8	64300	160000	2767
19	59	"	$3\frac{3}{16}$	58.8	56700	118000	2008
20	57	"	$3\frac{3}{16}$	58.8	39300	84600	1440
	Mean of 1-2-4 mixture						2145

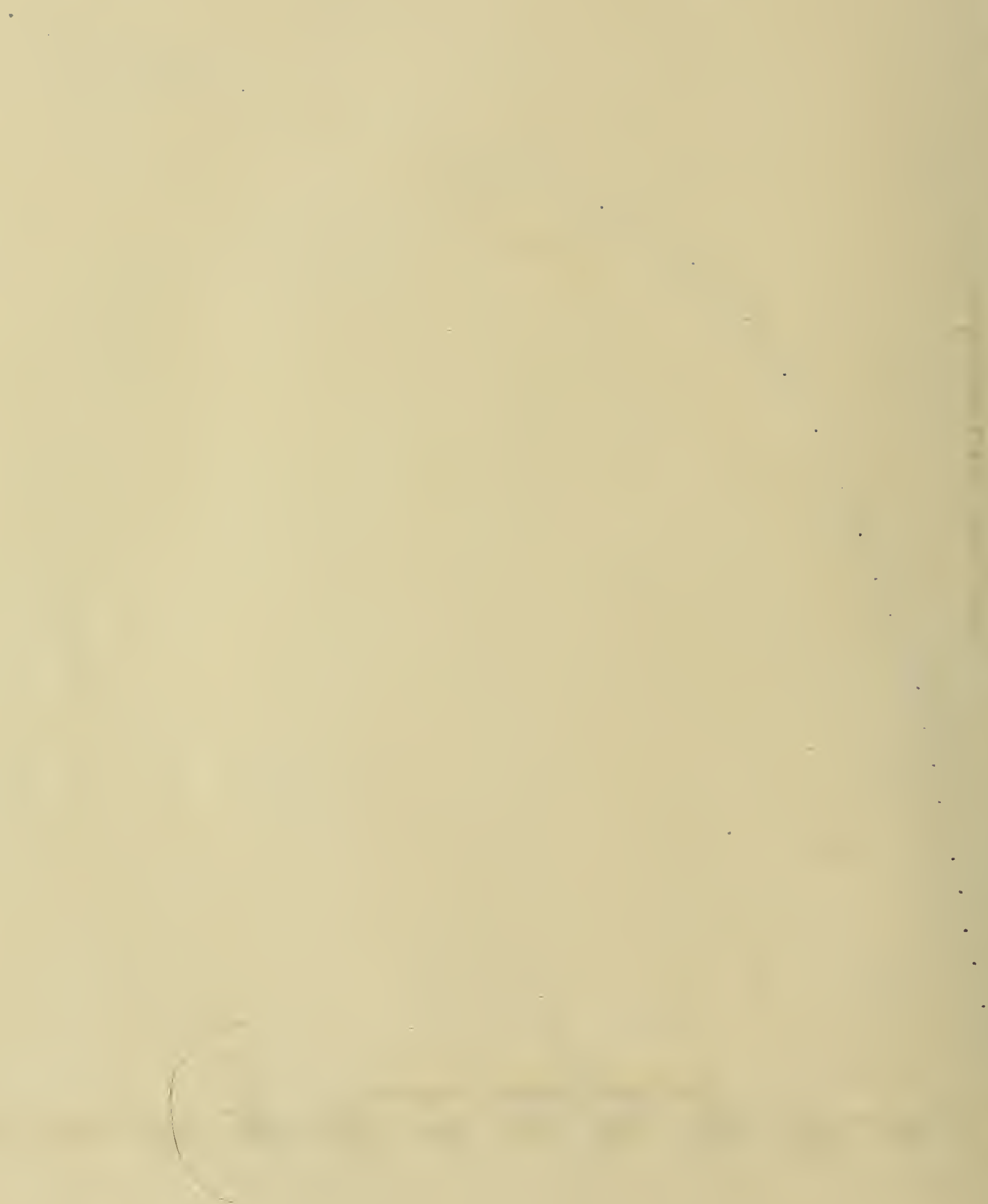
TABLE 5

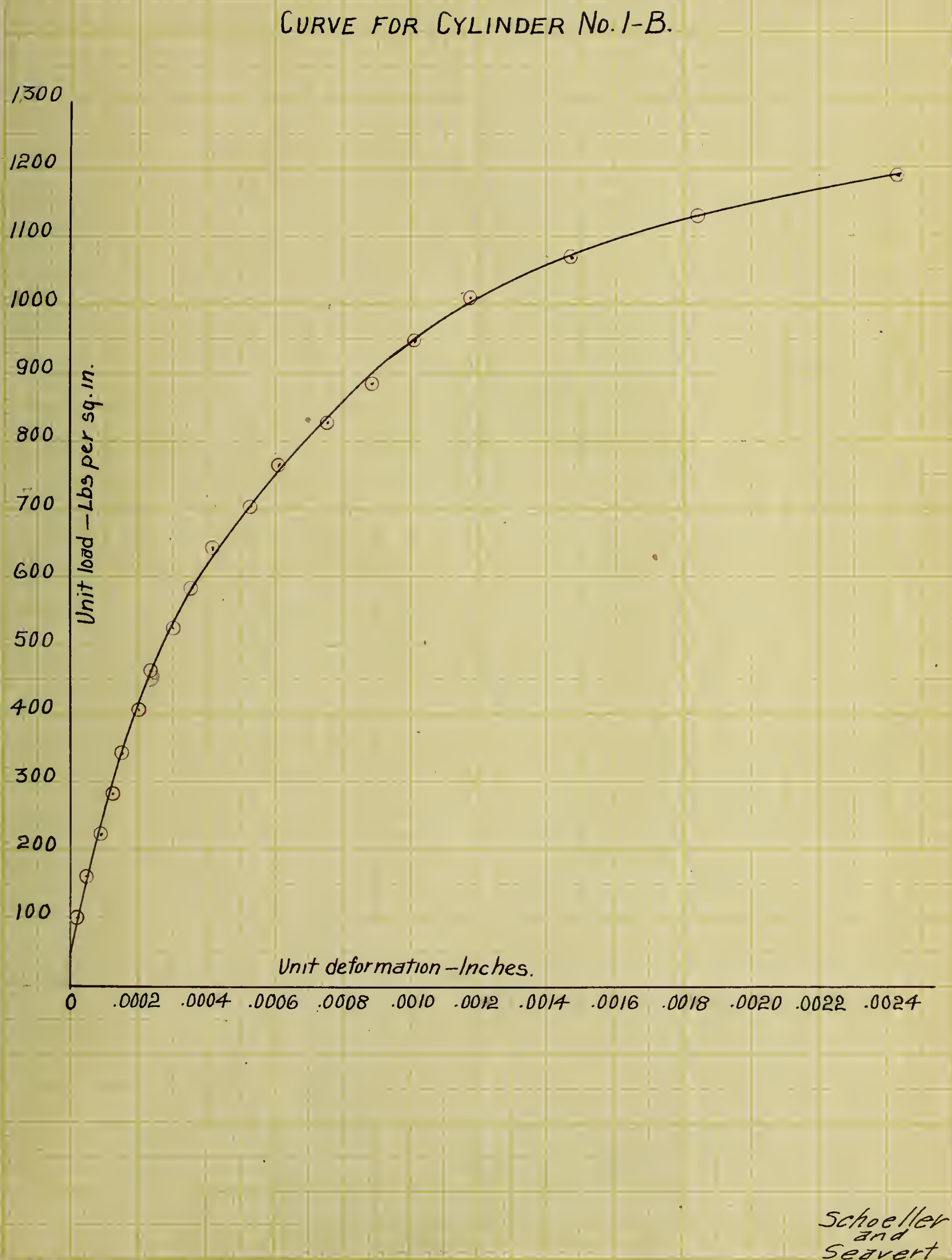
Data and Results — Cubes

Reference Number	Age Days	Compression Area: Surface inches	Compression Area: Area sq.ins.	Loads in pounds: First Crack	Loads in pounds: Ultimate Load	Unit Compression lbs/sq.in.
1A	60	$6\frac{1}{8}\times6\frac{3}{16}$	37.9	70000	73200	1930
1B	60	$6\frac{1}{8}\times6\frac{1}{8}$	37.5	72000	73500	1958
1C	60	$6\frac{3}{16}\times5\frac{7}{8}$	36.4	73500	74500	2045
2A	60	$6\frac{1}{8}\times6\frac{3}{16}$	37.9	58000	86200	2274
2B	60	$6\frac{1}{8}\times6\frac{3}{32}$	37.2	67000	79500	2135
2C	60	$6\frac{3}{16}\times5\frac{7}{8}$	36.4	48000	75600	2072
3A	61	$6\frac{1}{8}\times6\frac{1}{8}$	37.5	92000	100700	2685
3B	61	$6\frac{1}{16}\times6\frac{1}{8}$	37.1	92000	113600	3060
3C	61	$5\frac{15}{16}\times6\frac{1}{4}$	37.1	78000	109200	2945
4A	59	$6\times6\frac{3}{16}$	37.1	70400	101000	2722
4B	59	$5\frac{15}{16}\times6\frac{1}{4}$	37.1	84000	101800	2740
4C	59	$6\frac{3}{16}\times6\frac{1}{8}$	37.9	74000	97400	2568
5A	60	$6\frac{3}{16}\times6\frac{1}{16}$	37.1	59600	65800	1773
5B	60	$6\frac{1}{8}\times6\frac{1}{16}$	37.1	53100	66500	1791
5C	60	$6\frac{1}{8}\times6$	36.8	50100	58900	1600
Mean of 1-3-6 mixture, omitting No. 5						2428
6A	59	$5\frac{15}{16}\times6\frac{5}{16}$	37.1	109500	128500	3463
6B	59	$6\frac{3}{16}\times6\frac{1}{16}$	37.1	110000	129000	3480
6C	59	$6\frac{5}{16}\times6$	37.8	73400	121400	3212
7A	59	$5\frac{13}{16}\times6\frac{1}{8}$	35.6	96300	108000	3030
7B	59	$6\times6\frac{1}{8}$	36.8	104000	117600	3193
7C	59	$6\frac{1}{8}\times6\frac{1}{16}$	37.1	100600	120900	3259
8A	58	$6\times6\frac{1}{4}$	37.5	63400	124700	3322
8B	58	$6\times6\frac{5}{16}$	37.8	99900	143100	3790
8C	58	$6\frac{1}{4}\times6\frac{1}{16}$	37.8	86800	138000	3650
9A	59	$6\frac{1}{8}\times6$	36.8	79500	91900	2492
9B	59	$6\frac{1}{16}\times6$	36.4	98000	113700	3120
9C	59	$6\frac{1}{8}\times6\frac{1}{16}$	37.1	69300	99300	2675
10A	57	$6\frac{5}{16}\times5\frac{15}{16}$	37.1	64000	111200	2998
10B	57	$6\frac{1}{16}\times6\frac{3}{16}$	37.5	59100	98600	2630
10C	57	$6\times6\frac{1}{4}$	37.5	84300	106500	3840
Mean of 1-2-4 mixture						3210



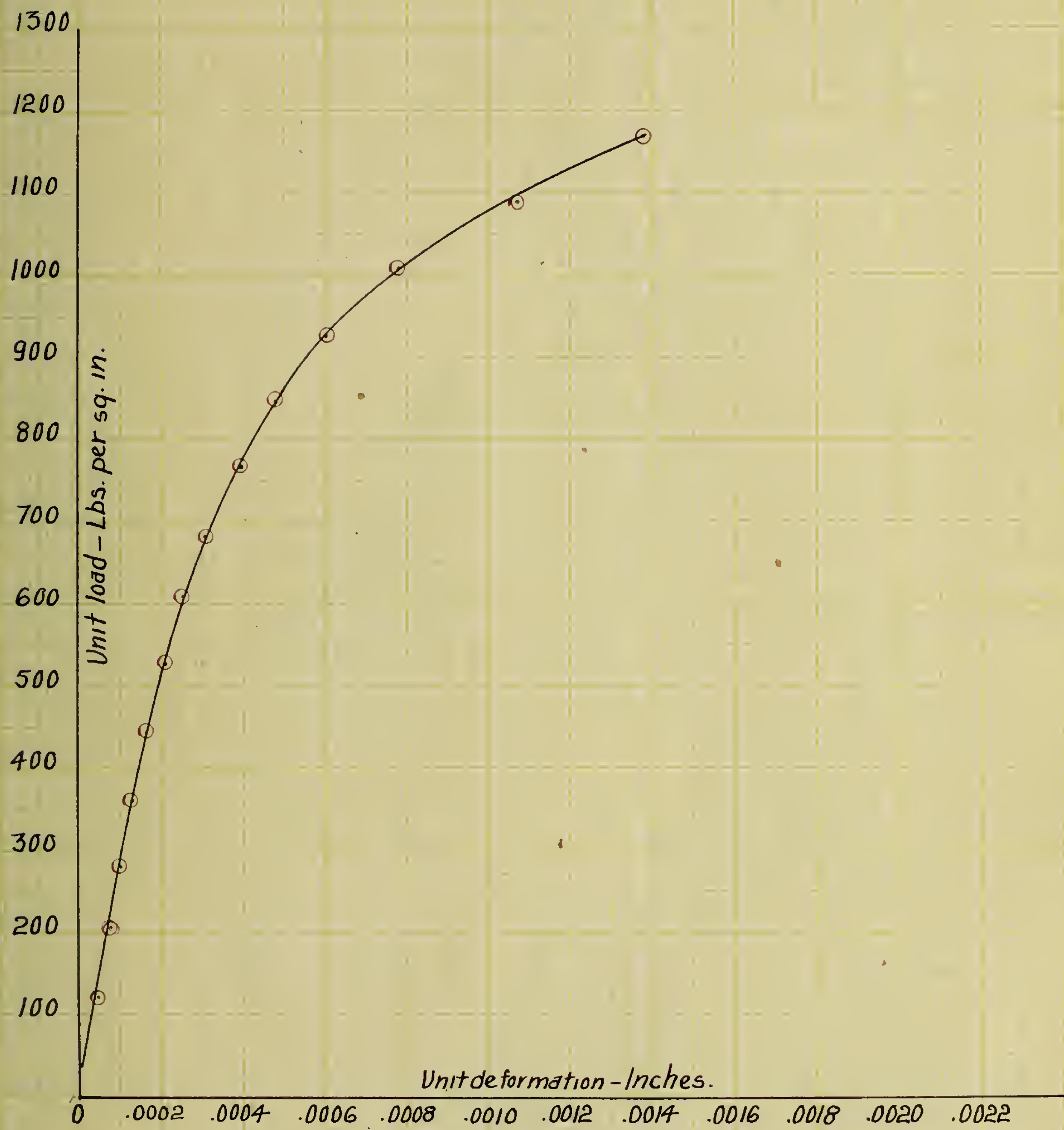
Schoeller and Seavert



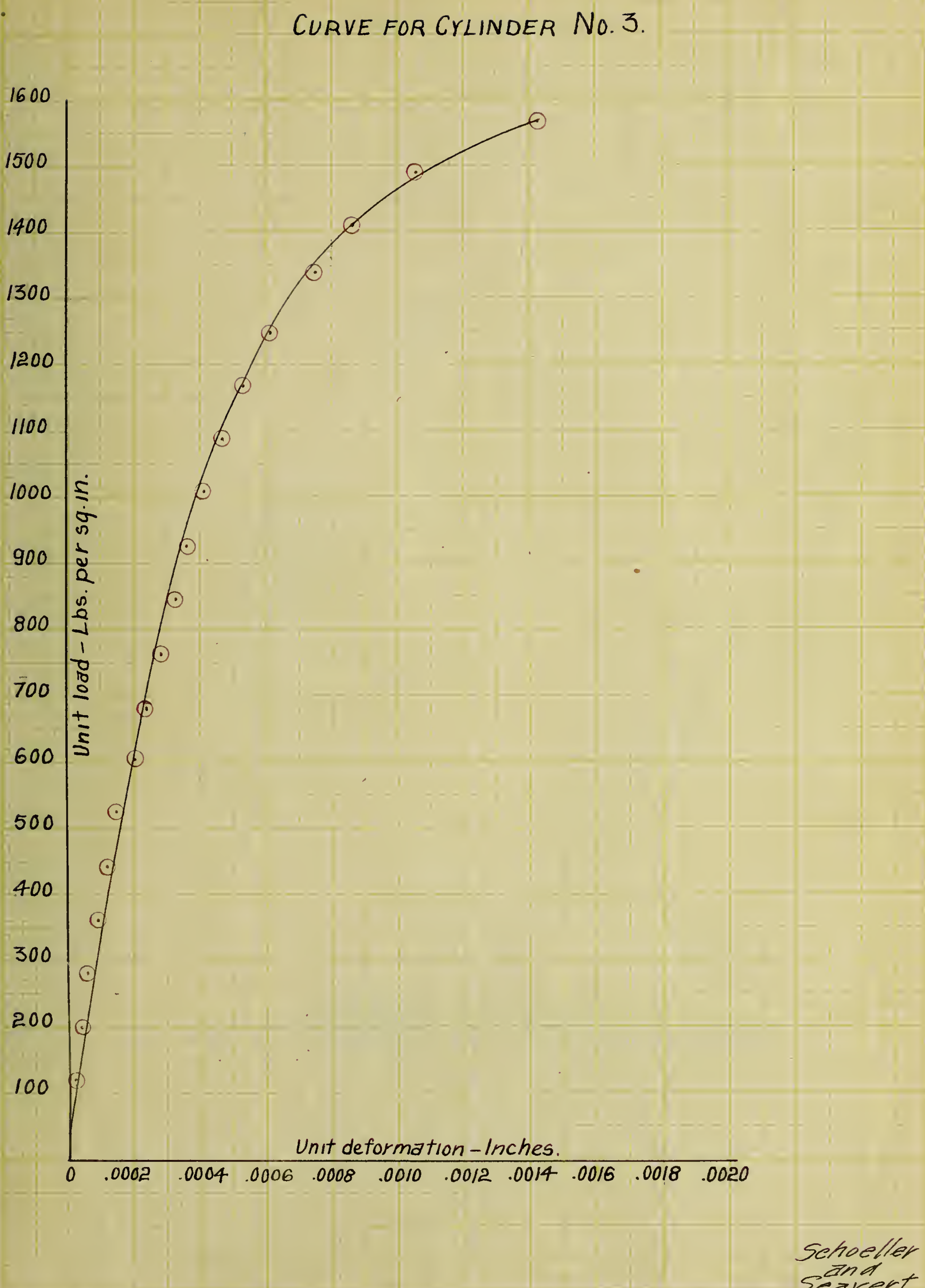


CURVE FOR CYLINDER No. 1-B.
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
Unit load — Lbs per sq. in.
Unit deformation — Inches.
0
.0002
.0004
.0006
.0008
.0010
.0012
.0014
.0016
.0018
.0020
.0022
.0024
Schoeller and Seavert

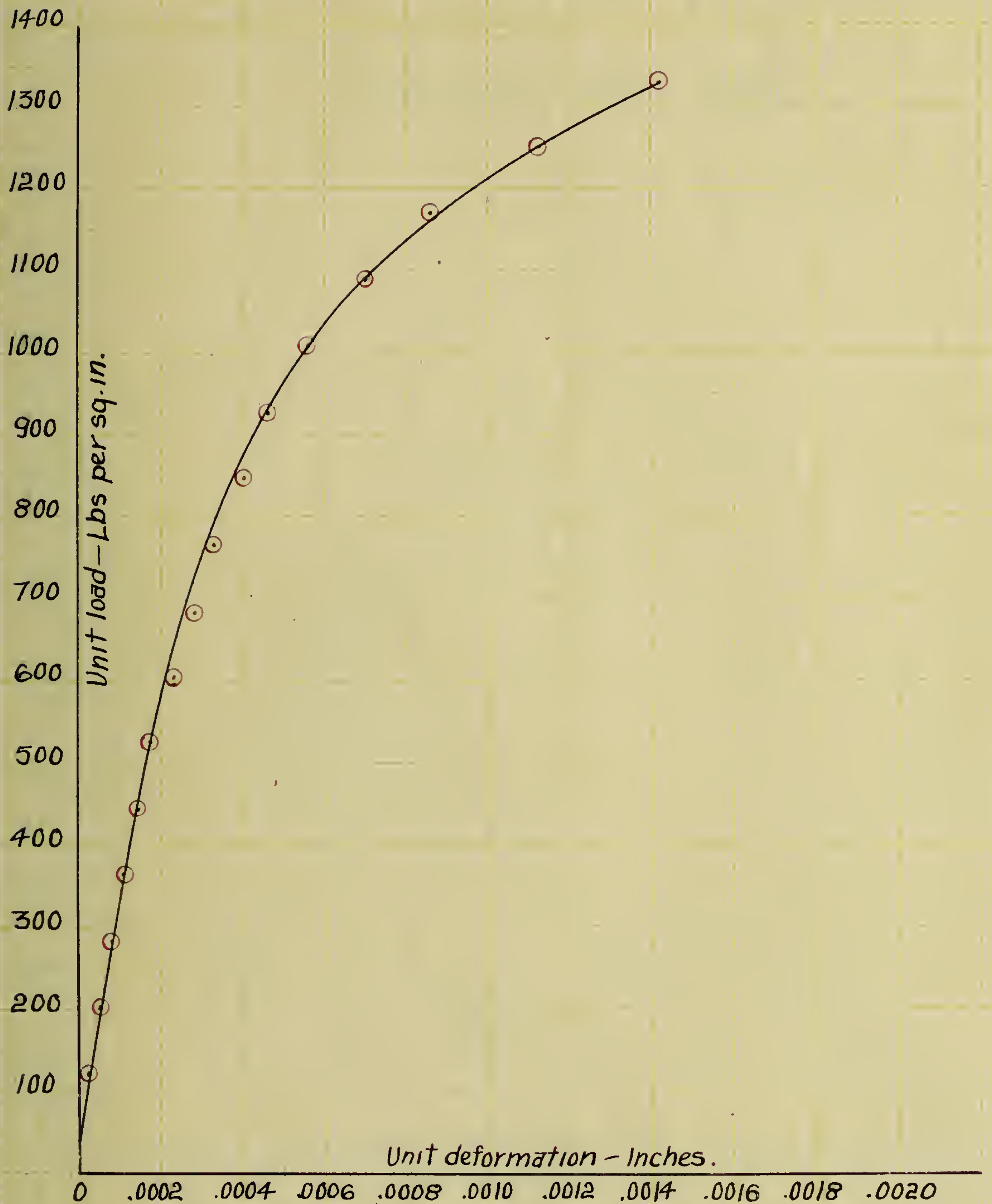
CURVE FOR CYLINDER No. 2.



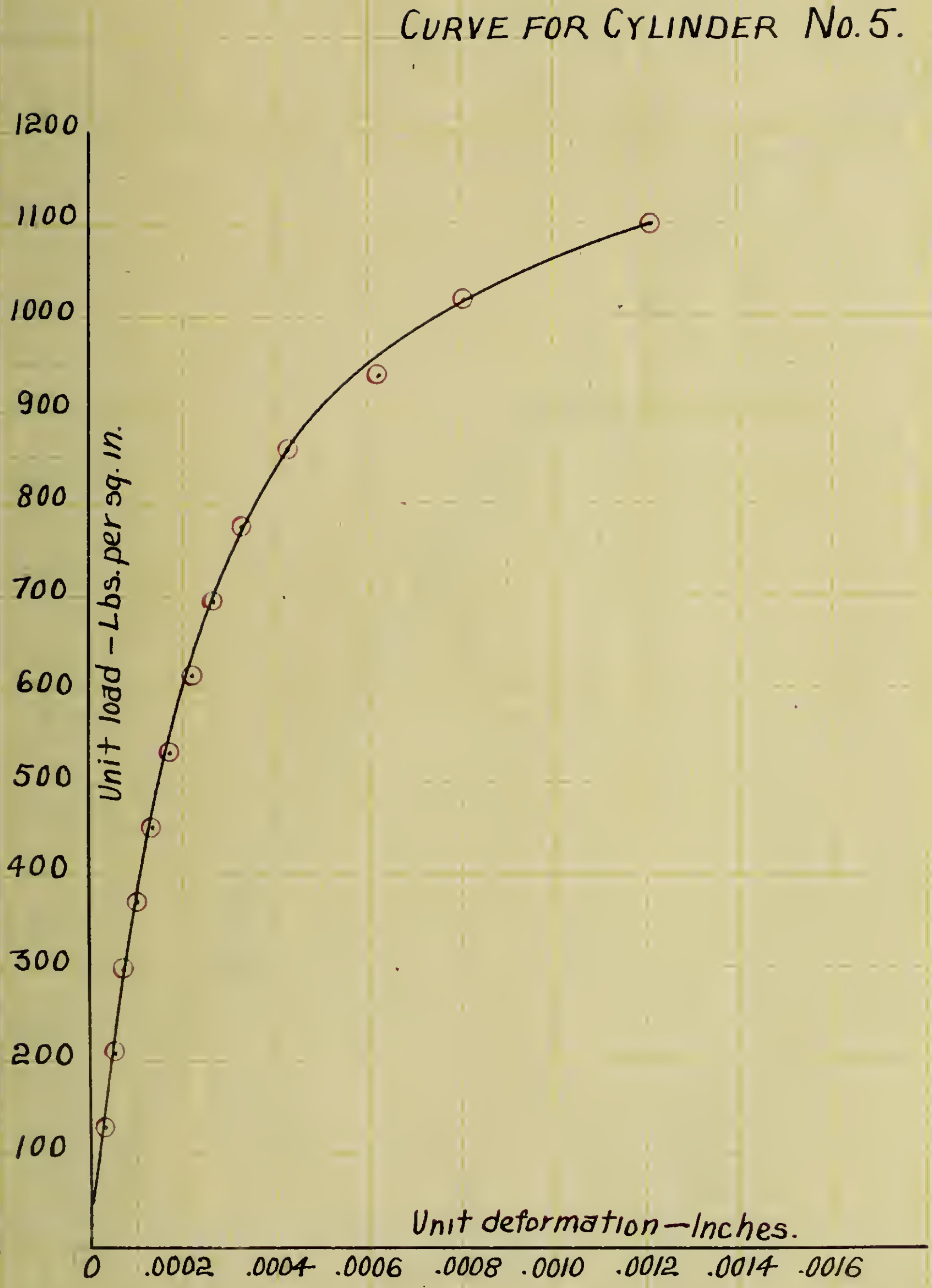
Schoeller
and
Seavert


Curve for Cylinder No. 3.
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
Unit load - Lbs. per sq. in.
Unit deformation - Inches.
0
.0002
.0004
.0006
.0008
.0010
.0012
.0014
.0016
.0018
.0020
Schoeller and Seavert

CURVE FOR CYLINDER No. 4.

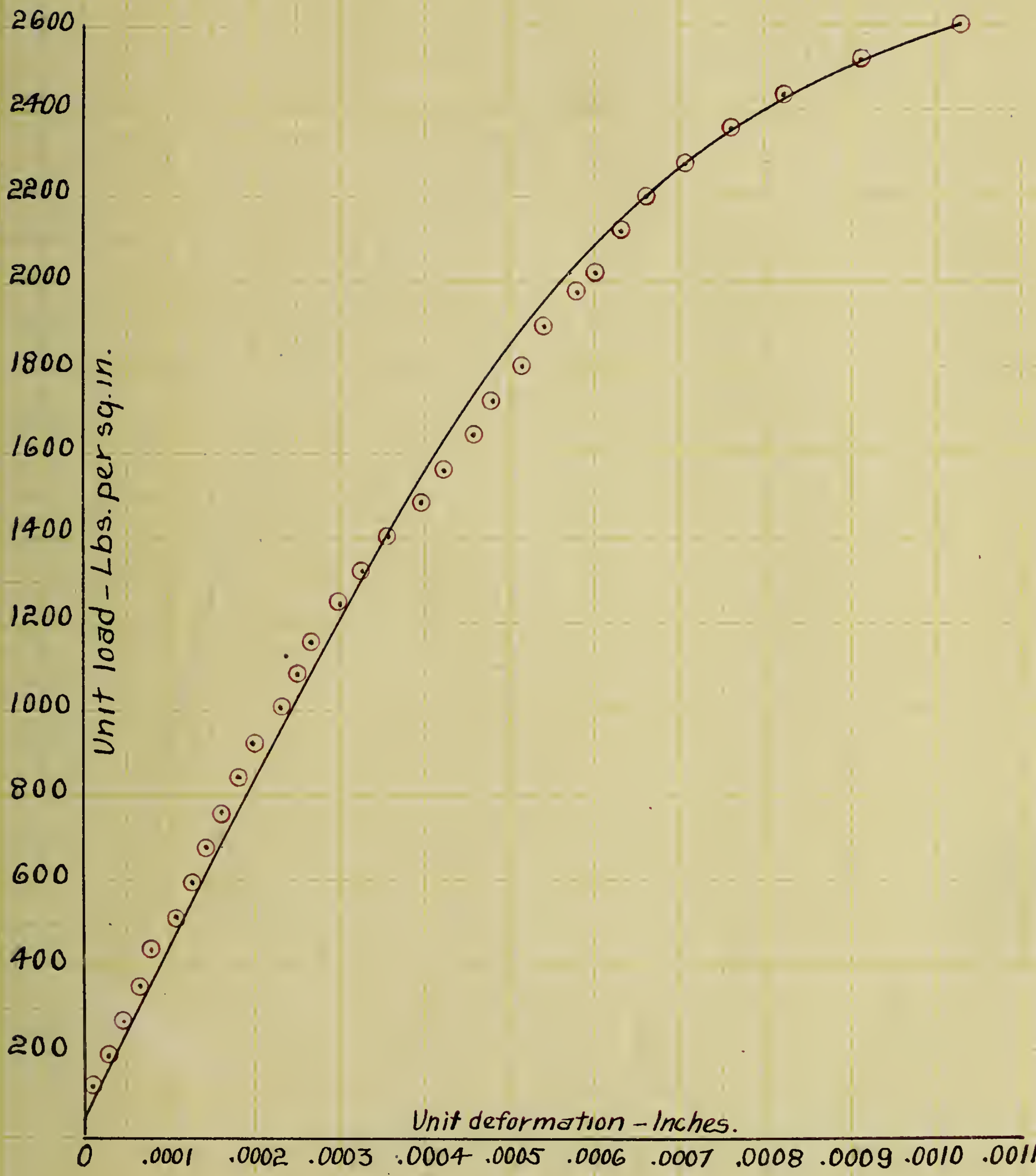


Schoeller and Seavert



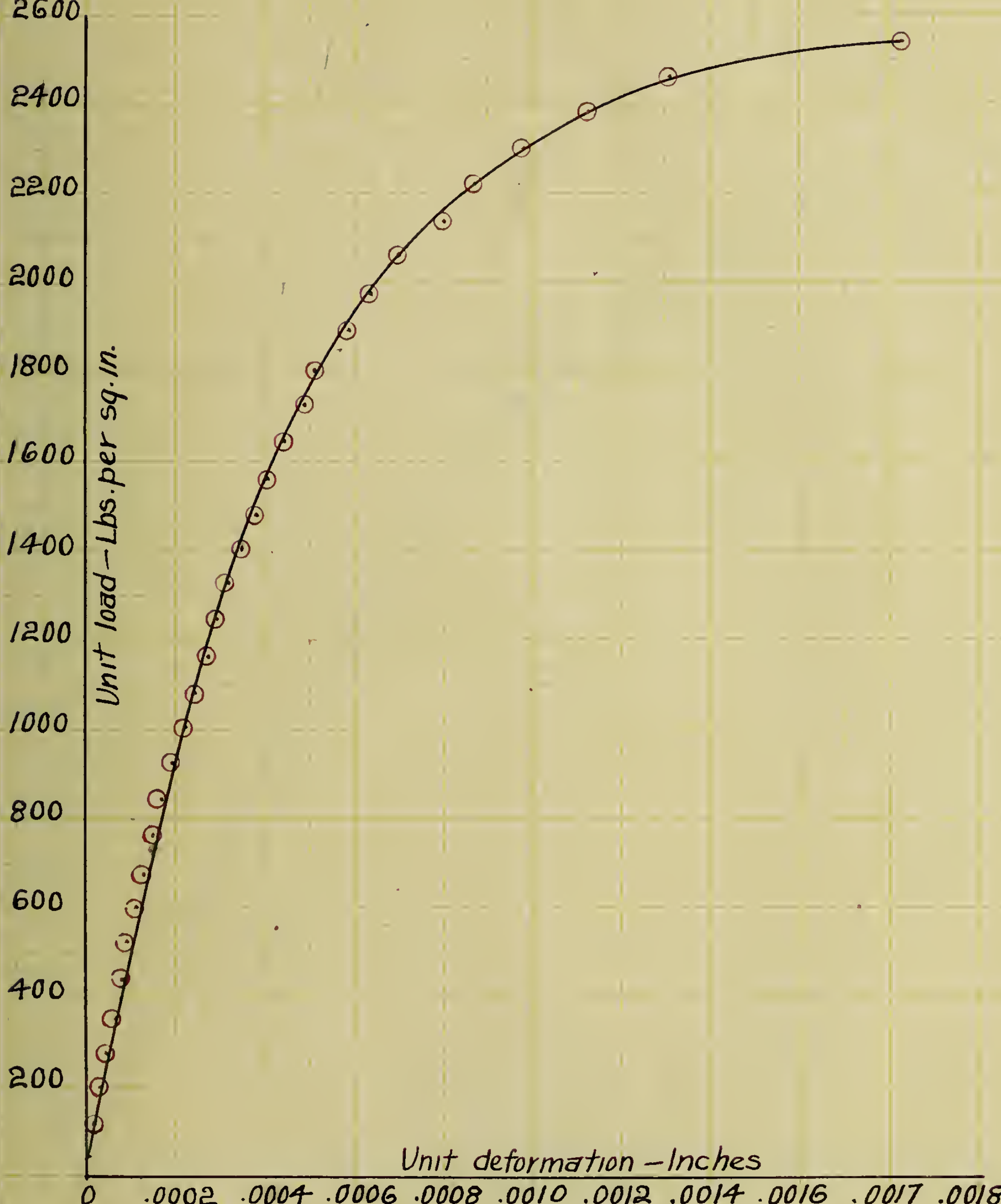
Schoeller
and
Seavert

CURVE FOR CYLINDER No. 6.

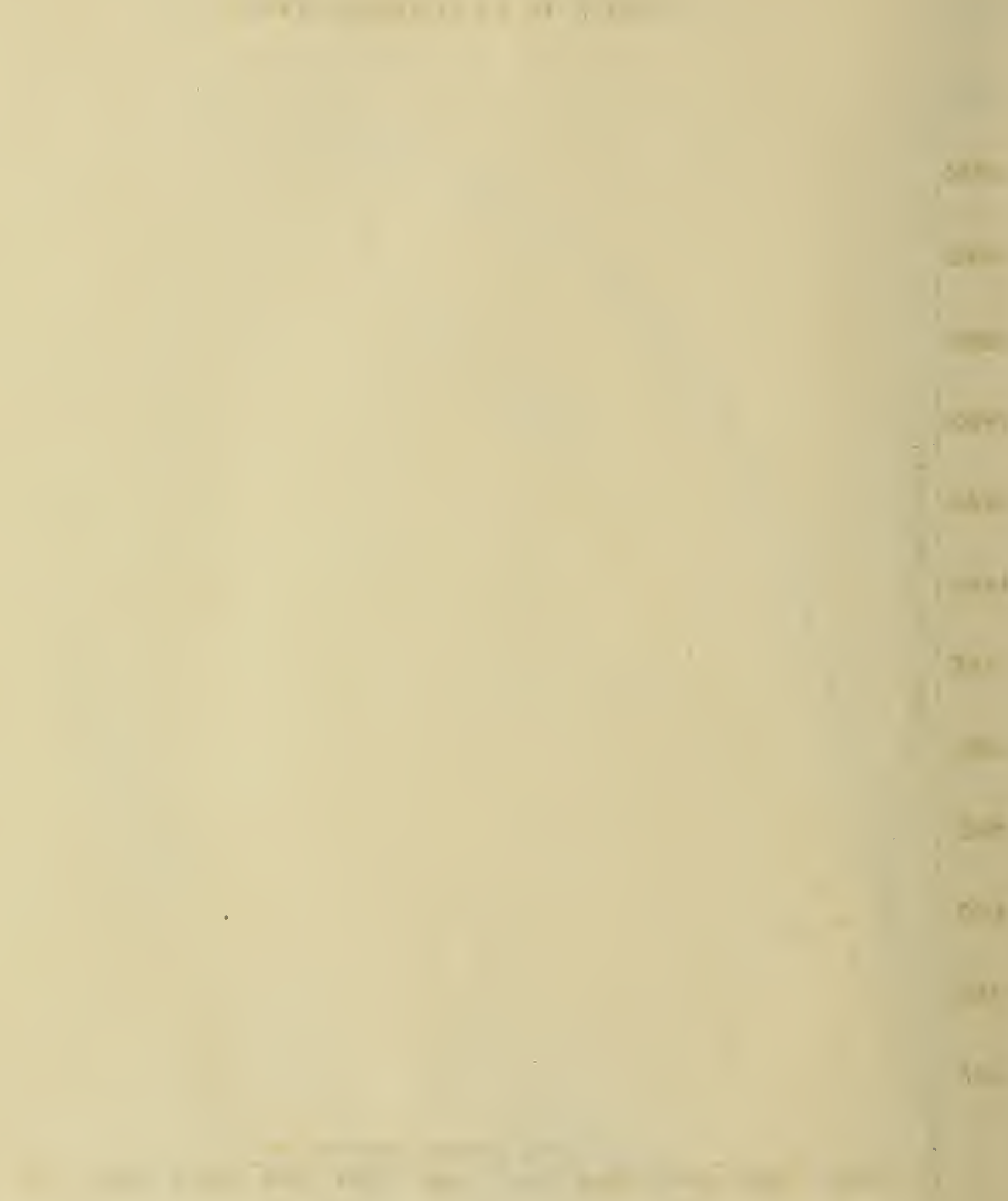


Schoeller
and
Seavert

CURVE FOR CYLINDER No. 8.



Schoeller
and
Seavert



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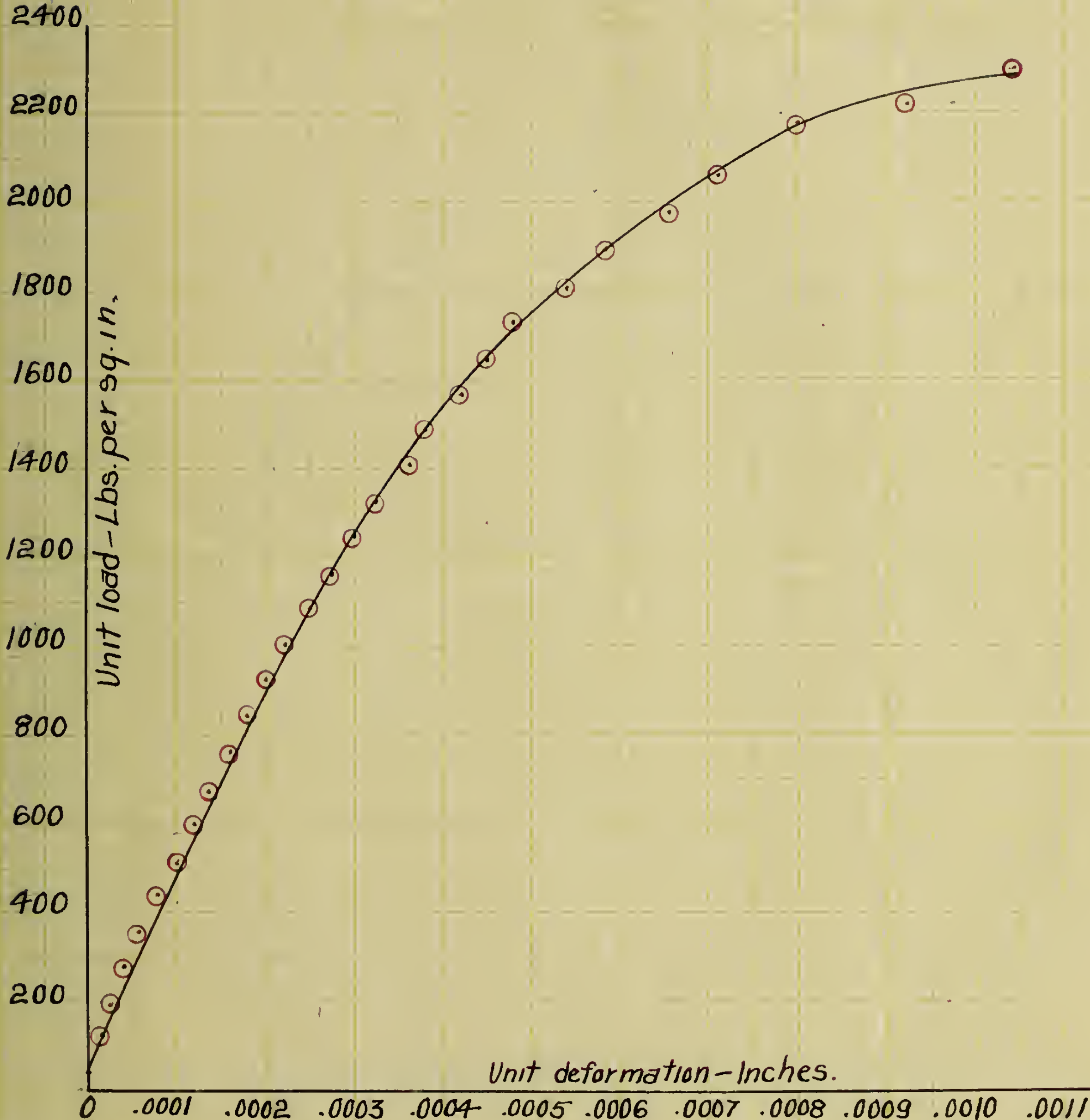
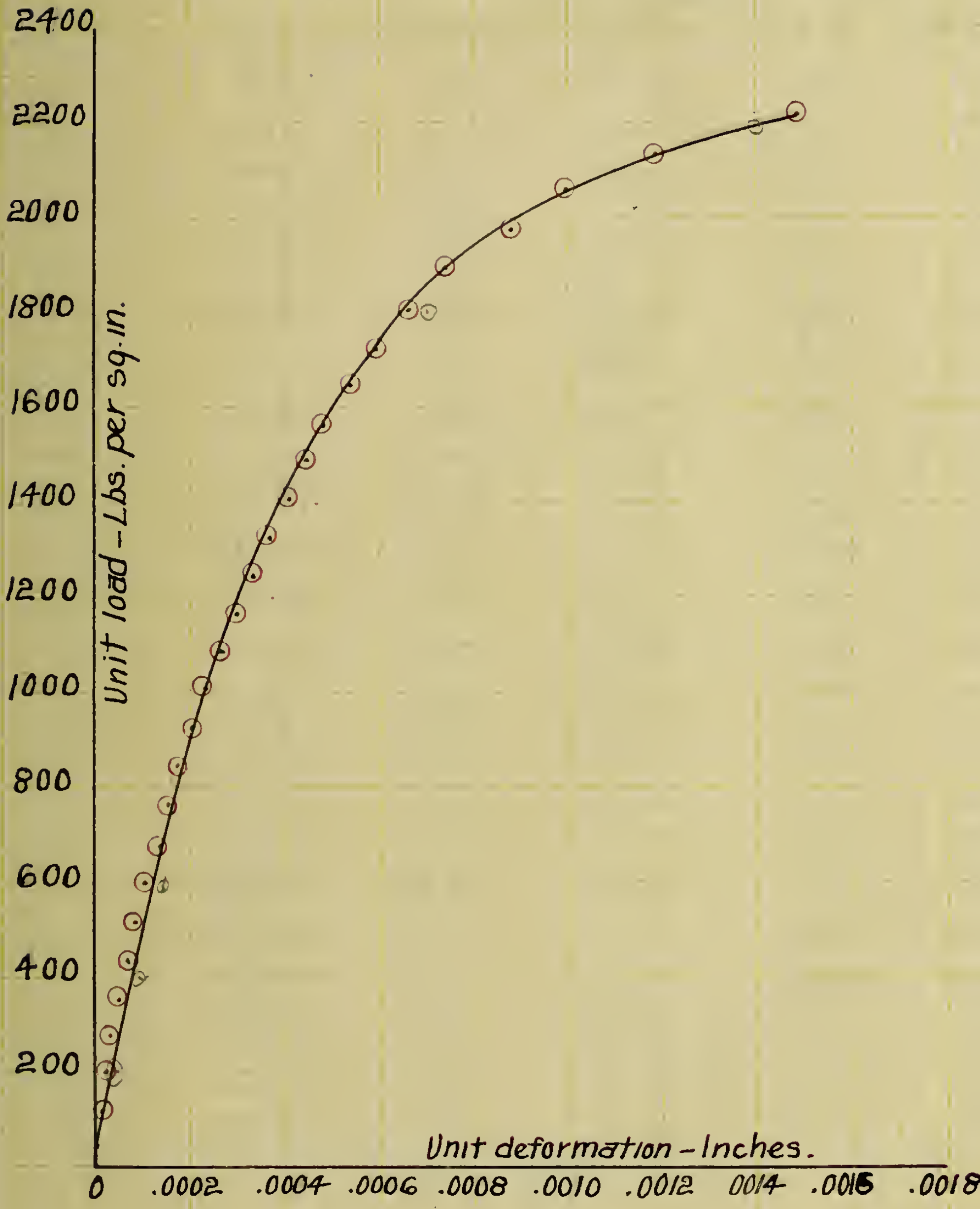


Schoeller and Seavert

CURVE FOR CYLINDER No. 10.



Schoeller
and
Seavert

Cylinder No. 1-A.

Age 60 Days. Mixture 1-3-6.

Total Load Lbs.	Unit Load lbs/sq. in.	Exten. reading–Inches. Upper	Exten. reading–Inches. Lower	Unit Deformation–Inches.
4000	81	.0000	.0000	.0000
6000	121	.0003	.0002	.000025
8400	170	.0006	.0004	.00005
10200	206	.0008	.0005	.000065
12300	248	.0010	.0006	.00008
14000	283	.0012	.0007	.000095
17200	347	.0015	.0010	.000125
19000	384	.0017	.0011	.00014
21000	424	.0019	.0014	.000165
23100	468	.0020	.0016	.00018
25000	505	.0022	.0019	.000205
27100	548	.0025	.0022	.000235
29100	588	.0028	.0026	.00027
31200	630	.0031	.0029	.00030
34000	685	.0036	.0033	.000345
37000	748	.0042	.0038	.00040
40000	805	.0049	.0046	.000475
43000	869	.0057	.0053	.00055
46000	929	.0066	.0068	.00067
49000	989	.0081	.0092	.000865
52000	1050	.0099	.0110	.001045
55000	1110	.0132	.0149	.001455
58000	1170	.0188	.0226	.00207
60500	1220	Maximum.		

Cylinder No. 1-B

Age 60 Days. Mixture 1-3-6

Total Load Lbs.	Unit Load lbs./sq. in.	Exten. reading-Inches		Unit Deformation-Inches
		Upper	Lower	
2200	44	.0000	.0000	.0000
5100	101	.0003	.0001	.00002
8100	164	.0007	.0002	.000045
11100	225	.0014	.0004	.00009
14100	285	.0020	.0005	.000125
17000	343	.0025	.0005	.00015
20000	404	.0035	.0005	.00020
23000	465	.0041	.0006	.000235
26100	528	.0053	.0007	.00030
29100	588	.0061	.0010	.000355
32000	646	.0072	.0011	.000415
35000	705	.0090	.0016	.00053
38000	769	.0100	.0022	.00061
41000	829	.0125	.0026	.000755
44000	888	.0149	.0028	.000885
47000	950	.0175	.0030	.001025
50000	1010	.0200	.0036	.00118
53000	1070	.0245	.0048	.001475
56000	1130	.0300	.0068	.00184
59000	1190	.0375	.0110	.002425
60000	1210	Maximum.		

Cylinder No. 2.

Age 60 Days. Mixture 1-3-6

Total Load Lbs.	Unit Load lbs./sq. in.	Exten. reading-Inches Upper.	Exten. reading-Inches Lower.	Unit Deformation-Inches
2000	40	.0000	.0000	.0000
6000	121	.0005	.0004	.000045
10100	204	.0011	.0004	.000075
14000	283	.0016	.0004	.00010
18000	364	.0022	.0004	.00013
22100	447	.0029	.0004	.000165
26200	530	.0036	.0005	.000205
30100	610	.0044	.0007	.000255
34000	685	.0050	.0011	.000305
38100	770	.0063	.0016	.000395
42000	849	.0075	.0021	.00048
46100	930	.0088	.0032	.00060
50000	1010	.0106	.0050	.00078
54000	1090	.0134	.0080	.00107
58000	1170	.0176	.0140	.00158
600.00	1210	Maximum.		

Cylinder No. 3.

Age 61 Days. Mixture 1-3-6.

Total Load Lbs.	Unit Load lbs/sq.in.	Exten. reading-Inches Upper	Exten. reading-Inches Lower	Unit Deformation-Inches
2000	40	.0000	.0000	.0000
6000	121	.0004	.0000	.00002
10000	200	.0010	-.0002	.00004
14000	283	.0015	-.0004	.000055
18000	364	.0021	-.0004	.000085
22000	445	.0027	-.0004	.000115
26100	528	.0034	-.0004	.00015
30000	605	.0040	.0000	.00020
34000	685	.0047	.0000	.000235
38000	769	.0056	.0000	.00028
42000	849	.0065	.0000	.000325
46000	929	.0072	.0000	.00036
50000	1010	.0082	.0000	.00041
54000	1090	.0094	.0000	.00047
58000	1170	.0106	.0000	.00053
62000	1250	.0120	.0002	.00061
66200	1340	.0145	.0004	.000745
70000	1410	.0162	.0010	.00086
74000	1490	.0195	.0016	.001055
78000	1570	.0225	.0030	.001425
80400	1630	Maximum.		

CYLINDER No. 4

AGE 59 DAYS. MIXTURE 1-3-6

Total Load Lbs.	Unit Load lbs./sq.in.	Exten. reading-Inches Upper	Exten. reading-Inches Lower	Unit Deformation-Inches.
2000	40	.0000	.0000	.0000
6100	123	.0004	.0000	.00002
10100	204	.0010	.0000	.00005
14200	287	.0016	.0000	.00008
18000	364	.0022	.0000	.00011
22100	447	.0029	.0000	.000145
26100	528	.0035	.0000	.000175
30000	605	.0045	.0001	.00023
34000	685	.0054	.0002	.00028
38000	769	.0061	.0004	.000325
42000	849	.0075	.0005	.00040
46000	929	.0088	.0006	.00046
50000	1010	.0104	.0008	.00056
54000	1090	.0124	.0015	.000695
58000	1170	.0150	.0021	.000855
62000	1250	.0190	.0034	.00112
66000	1330	.0220	.0064	.00142
66200	1340	Maximum.		

Cylinder No. 5.

Age 60 Days. Mixture 1-3-6.

Total Load Lbs.	Unit Load lbs./sq. in.	Exten. reading - Inches Upper	Exten. reading - Inches Lower	Unit Deformation - Inches.
2500	50	.0000	.0000	.0000
6500	131	.0004	.0003	.000035
10500	212	.0006	.0004	.00005
14800	300	.0008	.0006	.00007
18500	373	.0012	.0008	.00010
22500	454	.0017	.0010	.000135
26500	535	.0021	.0013	.00017
30500	616	.0027	.0017	.00022
34500	697	.0033	.0020	.000265
38500	778	.0041	.0024	.000325
42500	859	.0053	.0032	.000425
46500	940	.0075	.0048	.000615
50500	1020	.0094	.0066	.00080
54500	1100	.0135	.0107	.00121
57800	1160	Maximum.		

AGE 59 DAYS. CYLINDER No. 6. MIXTURE 1-2-4

Total Load Lbs.	Unit Load lbs./sq. in.	Exten. reading-Inches		Unit Deformation-Inches
		Upper	Lower	
2200	44	.0000	.0000	.0000
6000	121	.0002	.0000	.00001
10000	200	.0005	.0001	.00003
14000	283	.0007	.0002	.000045
18000	364	.0010	.0003	.000065
22000	445	.0012	.0004	.00008
26000	525	.0015	.0006	.000105
30000	605	.0018	.0007	.000125
34000	685	.0019	.0009	.00014
38000	769	.0022	.0010	.00016
42000	849	.0024	.0012	.00018
46000	929	.0026	.0013	.000195
50000	1010	.0030	.0016	.00023
54000	1090	.0032	.0018	.00025
58000	1170	.0034	.0019	.000265
62000	1250	.0038	.0022	.00030
66000	1330	.0042	.0023	.000325
70000	1410	.0046	.0025	.000355
74000	1490	.0049	.0030	.000395
78000	1570	.0053	.0031	.00042
82000	1650	.0058	.0033	.000455
86000	1730	.0061	.0035	.00048
90000	1810	.0066	.0036	.00051
94000	1900	.0071	.0037	.00054
98000	1980	.0078	.0038	.00058
101000	2040	.0082	.0038	.00060
105000	2120	.0088	.0038	.00063
109000	2200	.0092	.0040	.00066
113000	2280	.0099	.0042	.000705
117000	2360	.0110	.0042	.00076
121000	2440	.0121	.0043	.00082
125000	2520	.0135	.0047	.00091
129000	2600	.0155	.0052	.00103
132000	2660	Maximum.		

Cylinder No. 8

Age 58 Days — Mixture 1-2-4

Total Load Lbs.	Unit Load lbs./sq.in.	Exten. reading–Inhes Upper	Exten. reading–Inhes Lower	Unit Deformation-Inches
2200	44	.0000	.0000	.0000
6000	121	.0002	.0000	.00001
10000	200	.0004	.0001	.000025
14000	283	.0006	.0002	.00004
18000	364	.0008	.0004	.00006
22000	445	.0010	.0005	.000075
26000	525	.0013	.0005	.00009
30000	605	.0016	.0006	.00011
34000	685	.0018	.0007	.000125
38000	769	.0020	.0009	.000145
42000	849	.0022	.0011	.000165
46000	929	.0025	.0013	.00019
50000	1010	.0029	.0015	.00022
54000	1090	.0031	.0017	.00024
58000	1170	.0035	.0018	.000265
62000	1250	.0038	.0020	.00029
66000	1330	.0042	.0021	.000315
70000	1410	.0045	.0024	.000345
74000	1490	.0050	.0026	.00038
78000	1570	.0053	.0027	.00040
82000	1650	.0058	.0030	.00044
86000	1730	.0065	.0032	.000485
90000	1810	.0073	.0037	.00055
94000	1900	.0078	.0039	.000585
98000	1980	.0085	.0041	.00063
102000	2060	.0095	.0044	.000695
106000	2140	.0110	.0050	.00080
110000	2220	.0120	.0054	.00087
114000	2300	.0135	.0061	.00098
118000	2380	.0155	.0069	.00112
122000	2460	.0184	.0078	.00131
126000	2540	.0245	.0100	.001725
126000	2540	Maximum		

Cylinder No. 9.

Age 59 Days   Mixture 1-2-4

Total Load Lbs.	Unit Load lbs./sq. in.	Exten. reading - Inches Upper	Exten. reading - Inches Lower	Unit Deformation - Inches
2000	40	.0000	.0000	.0000
6000	121	.0003	.0000	.000015
10000	200	.0005	.0000	.000025
14000	283	.0008	.0000	.00004
18000	364	.0012	.0000	.00006
22000	445	.0016	.0000	.00008
26000	525	.0019	.0001	.00010
30000	605	.0023	.0001	.00012
34000	685	.0026	.0001	.000135
38000	769	.0031	.0001	.00016
42000	849	.0035	.0001	.00018
46000	929	.0039	.0001	.00020
50000	1010	.0043	.0002	.000225
54000	1090	.0048	.0002	.00025
58000	1170	.0053	.0002	.000275
62000	1250	.0057	.0003	.00030
66000	1330	.0061	.0004	.000325
70000	1410	.0067	.0005	.00036
74000	1490	.0071	.0005	.00038
78000	1570	.0079	.0005	.00042
82000	1650	.0084	.0006	.00045
86000	1730	.0090	.0008	.00048
90000	1810	.0098	.0010	.00054
94000	1900	.0105	.0012	.000585
98000	1980	.0116	.0015	.000655
102000	2060	.0125	.0017	.00071
106000	2140	.0140	.0020	.00080
110000	2220	.0159	.0026	.000925
114000	2300	.0180	.0029	.001045
114000	2300	Maximum.		

Cylinder No. 10

Age 57 Days. Mixture 1-2-4

Total Load Lbs.	Unit Load lbs/sq. in.	Exten. reading-Inches Upper	Exten. reading-Inches Lower	Unit Deformation-Inches.
2000	40	.0000	.0000	.0000
6000	121	.0002	.0000	.00001
10000	200	.0004	.0000	.00002
14000	283	.0006	.0000	.00003
18000	364	.0008	.0001	.000045
22000	445	.0011	.0002	.000065
26000	525	.0013	.0003	.00008
30000	605	.0016	.0005	.000105
34000	685	.0020	.0008	.00014
38000	769	.0022	.0009	.000155
42000	849	.0025	.0010	.000175
46000	929	.0028	.0013	.000205
50000	1010	.0031	.0016	.000235
54000	1090	.0036	.0018	.00027
58000	1170	.0040	.0020	.00030
62000	1250	.0045	.0022	.00033
66000	1330	.0050	.0024	.000375
70000	1410	.0055	.0027	.00041
74000	1490	.0060	.0029	.000445
78000	1570	.0066	.0032	.00048
82000	1650	.0073	.0035	.00054
86000	1730	.0081	.0038	.000595
90000	1810	.0090	.0043	.000665
94000	1900	.0101	.0049	.00075
98000	1980	.0119	.0057	.00088
102000	2060	.0132	.0067	.000995
106000	2140	.0153	.0084	.001185
110000	2220	.0183	.0115	.00149
110000	2220	Maximum.		